Memorandum

Environment and Resources
55 Wheeler Street, Cambridge, MA ◆ Tel: 617 492-7100 ◆ www.abtassociates.com

Abt Associates Inc.

Date	July 7, 2010
To	Ashley Allen and Jason Berner, U.S. Environmental Protection Agency (EPA)
From	Viktoria Zoltay, Ryan Stapler, David Mitchell and Elena Besedin, Abt Associates
Subject	Updated Preliminary Environmental Assessment Literature Review for the Post-Construction and Development Stormwater Rulemaking

1. Introduction

Abt Associates conducted a preliminary literature review to identify, acquire and review an initial set of literature in support of the environmental assessment analyses for the post-construction and development rulemaking. The purpose of the literature review is to conduct a reconnaissance of the relevant literature under the topics of interest, identify influential (i.e., widely-cited) papers for content and to support identification of potential experts, and check for data gaps in the available information. We will further refine this information and expand the literature database over the course of the project.

2. Methodology

In this initial effort, we focused primarily on peer-reviewed literature, conducted searches using key words derived from the subject areas of interest. From the raw results, we assembled a Zotero bibliographic database with over one thousand papers on the range of topics described in the literature review outline. We categorized these papers according to the outline topics (recognizing that many papers overlap several topics) and selected the more relevant and/or most cited papers. We reviewed the abstracts of these selected papers and the full text of some review papers to provide a summary of the specific topics, ideas and trends discussed in the relevant literature. We reference a few authors at the end of some sections who appear to publish frequently on certain topics. A more direct assessment can be made of the “most cited” or “most published” authors for different topics using the Zotero database.

3. Literature Review Annotated Outline

1. Overview of the effects of urban development

Urban development has multiple interrelated impacts on the environment including land cover/ land use and air, soil and water resources (Duha, Shandas et al. 2008; Hall, Ahmed et al. 2009). In this preliminary literature review, we focused on identifying and reviewing literature that documented the effects of land cover/land use changes on water resources due to urbanization.

a. Land Use Changes

Specific statistics of patterns and trends of land use changes in the United States were not found in the current set of peer-reviewed literature, these values are more readily available in government publications and data sets. Studies in the peer-reviewed literature do utilize government sources of data such as the U.S. Census Bureau for characterizing changes in populations and urbanization (e.g., Paul and Meyer 2001). Another example of a useful government data source is the U.S. Geological Survey's (USGS's) Urban Dynamics Research Program that studies long-term changes in urbanization and land cover using historic data. The program includes regional studies of the pace and extent of urbanization with the goal of providing data and predictions for sound policy (USGS 2004). Cuo, Lettenmaier et al. (2009) is an example of a region or basin specific study which analyzes long-term trends in land use change and the resulting environmental impacts. Also, the USGS (2009) has developed a national urban intensity index using data from nine metropolitan areas in the U.S. for comparing changes in physical, chemical, and biological characteristics along gradients of urban intensity both locally and nationally.

An example of the types of papers that may be available on landscape level (i.e., macroscale) impacts of urbanization is a study by DiBari (2007) which examined the effects of urbanization on landscape structure as indicated by patch size, shape or dispersion. In addition, the peer-reviewed literature in other topic sections typically cite the magnitude of changes in urban areas or impervious cover when reporting results for the corresponding changes in environmental variables; again indicating that this information will be available (Cianfrani, Hession et al. 2006; Kauffman, Belden et al. 2009; O'Driscoll, Soban et al. 2009).

Many studies document the effects of converting forest land to urban, suburban or agricultural land use while others compare urban to mixed use or urban to agricultural land uses (Booth and Jackson 1997; Chang 2007; Line and White 2007; Bressler, Paul et al. 2009; Poff, Richter et al. 2010). In general, the environmental impacts of land use changes are more pronounced with a greater shift (either in acreage or in development intensity) away from the pre-development land cover.

b. Land Use/Stormwater Management Policies

There are several studies that discuss the adverse effects of land use change, the ineffectiveness of current stormwater management policies and propose alternative approaches (Booth, Hartley et al. 2002; Brabec 2009; Mejia and Moglen 2009). In general, most conclude that the best approach to reducing impacts is to require mimicking pre-development hydrologic regimes. For example, Mejia and Moglen (2009) found that policies based on imperviousness thresholds resulted in unintended consequences of low density sprawl. In King County, WA, there have been 20 years of progressively more stringent stormwater management requirements that have mitigated flooding and erosion but were not able to restore conditions similar to the pre-development hydrologic regime or aquatic habitat necessary to mitigate impacts on biota (Booth, Hartley et al. 2002). In addition, a couple of papers point to the effect of development outside the scope of current stormwater management regulations such as the conversion of forest to pasture or lawn in rural areas and the cumulative effect of small development projects (Booth and Jackson 1997; Booth, Hartley et al. 2002). In a review by Brabec (2009) on development and hydrologic impairment, two potentially important factors are identified as being overlooked – the location of impervious surface and the maintenance of adequate forest and native vegetation. These papers point to the complexity of devising land use and stormwater management policies that are effective in restoring and/or protecting water resources. Seeking out additional summary articles documenting the effectiveness or lack of effectiveness of management policies may be valuable.

c. Climate Change and Land Use Effects

A few papers tried to differentiate between the effects of changes in climate versus land use on water resources. The general conclusion is that local circumstances determine which effect is more dominant and, therefore, cause the observed changes in the hydrologic regime (Cuo, Lettenmaier et al. 2009; Praskievicz and Chang 2009). For example, Hejazi and Markus (2009) found that among 12 small urbanizing watersheds, on average, urbanization caused 34% greater increase in peak flows than climate variability. In some cases, the effects of land use and climate change exacerbate while in other cases mediate each others' impacts (Praskievicz and Chang 2009). Urbanization can also cause additional, local climate change in the form of urban-induced rainfall (Changnon and Westcott 2002; Shephard 2005; Pielke, Beltran-Przekurat et al. 2006).

d. Impact of Land Use Changes on Natural Resources

In general, the effects of land cover change propagate to stream biota through the following cascade – land use changes alter the hydrologic regime of the stream which changes the channel geomorphology (and therefore, aquatic habitat characteristics) and water quality of the stream which, in turn, affect the stream biota (Burcher, Valett et al. 2007).

Several papers note the importance of spatial and temporal scale, climate variability and basin characteristics (e.g., elevation, relief, connectivity of impervious areas, characteristics of receiving channels) as important factors in detecting the environmental effects of urbanization (e.g., Booth and Jackson 1997; Bledsoe and Watson 2001; Cianfrani, Hession et al. 2006; Chang 2007). Numerous studies document increases in stressors to aquatic life due to land use changes from development such as nutrients levels (e.g., Carle, Halpin et al. 2005; Cunningham, O'Reilly et al. 2009) and roadway runoff (e.g., Wu, Allan et al. 1998).

With extensive documentation of urban effects on water resources, there also appear to be more recent studies trying to quantify the effects of suburban development. For example, Cunningham, O'Reilly et al. (2009) document that in five suburban headwater streams ranging in impervious cover from 4.7% to 34%, elevated concentrations of chloride and nitrate levels were found relative to reference conditions.

Topographic alterations due to development include the filling of depressions and low-areas which would otherwise collect or decelerate runoff and can include small alterations such as detention ponds or roadway embankments (USGS 1983). Topographic alterations due to urbanization also include the physical burial of headwater streams; one study found that 20% of headwater streams were buried within a study area near Chesapeake Bay (Elmore and Kaushal 2008). Topographic variables such as drainage area, channel length, valley length, stream slope, and soil classification have been included in past USGS modeling efforts for urban watersheds and flood characteristics in urban watersheds (e.g., USGS 1983). Studies of the physical impacts from development near surface water resources, such as channel widening, are readily available in the literature (e.g., Leopold, Huppman et al. 2005; Galster, Pazzaglia et al. 2008).

Man-made structures within a channel or floodplain can cause channel narrowing and resistance to flow resulting the scouring of the channel bed and banks or backwater (USGS 1983). USGS provides an extensive literature on bridge scour under the National Bridge Scour Program, implemented to measure and monitor these impacts. Due to its implications for public safety, reports on bridge scour tend to focus on impacts to bridge structures. Some reports also document impacts to the channel bed and stream bank (e.g. Richardson and Huber 1991; USGS 2002; USGS 1994; USGS 1997).

Development and other anthropogenic effects can result in changes in the quality and quantity of sediment (Owens, Battala et al. 2005). However, literature identified thus far is primarily focused on impacts from dam, reservoirs, and other man-made impoundments. These structures can significantly reduce the sediment supply and lead to sediment starvation in downstream areas such as the Gulf of California (e.g., Carriquiry, Sanchez et al. 2001; Owens, Battala et al. 2005). Downstream impacts can also include reduced wetland sedimentation and nourishment (White, Morton et al. 2002; Stevenson, Ward et al. 1988).

e. Impervious Surfaces

In examining the environmental impact of urbanization, numerous studies use impervious surface cover as a quantitative indicator of urbanization (e.g., Booth 1991, Stanfield and Kilgour 2006). The effects of different percent impervious surface (IS) are often measured by hydrogeomorphic (e.g., channel stability (Stanfield and Kilgour 2006)) and biotic indicators (e.g., diversity of fish assemblages (Helms et al. 2009)).

Of the seven reviewed studies that examined the effects of IS on the hydrogeomorphic characteristics of streams, all found impacts from an increasing percentage of IS (Cianfrani et al. 2006; Colosimo and Wilcock 2007; Stanfield and Kilgour 2006; Helms et al 2009; Roy et al. 2003; Booth 1991; Bledsoe and Watson 2001). Cianfrani et al. (2006) analyzed 46 independent stream reaches in Southeastern Pennsylvania and found two significant relationships when analyzing the entire dataset across an IS range of 0-75 percent: (1) increasing IS and decreasing sinuosity and (2) increasing IS and increasing large woody debris. They noted different trends in pool depth and embeddedness in reaches with less than 13 percent IS and greater than 24 percent IS. They concluded that “stream reach response to urbanization may not be consistent across geographical regions and that local conditions (specifically riparian buffer vegetation) may significantly affect channel response (Cianfrani et al. 2006).” The localized and reach specific effects of urbanization were also noted by Colosimo and Wilcock (2007) who found both enlargement and reduction of channel size. Reach specific effects depended on “the extent of upstream development, the timing and location of urbanization and upstream channel adjustment, and the presence of hydrologic constrictions and grade controls (Colosimo and Wilcock 2007).” For example, if one reach is experiencing erosion, the sediment from that reach can serve as a sediment source and cause aggredation in downstream reaches. Roy et al. (2003) correlated increasing urban land use with decreasing stream bed sediment size and increasing total suspended solids.

Several studies, such as Stanfield and Kilgour (2006), tried to determine thresholds where IS impacts become significant and/or detrimental to the environment. Stanfield and Kilgour (2006) analyzed over 575 wadeable stream sites and found that there were no cold water sites among sites with greater than 8 percent IS and no narrow streams among site with greater than 10 percent IS. Booth (1991) found a rapid decline in channel stability above 10 percent IS. Bledsoe and Watson (2001) drew similar conclusions, stating that above 10 to 20 percent IS stream channels may destabilize. Riley et al. (2005) detected the effects of urbanization above 8 percent urban development as seen by fewer pool and more run habitats and increased water depth and flow. It is likely that the 8 percent urban development represents less than 8 percent IS and, therefore, suggests a lower threshold for noticing the effects of urbanization on the hydrogeomorphology of streams than the other studies that found responses at greater than 8 and 10 percent IS. White and Greer (2008) also used percent urban land instead of IS and found that the effects of increasing urban area included increase incising and increased total runoff. However, their dataset only had 9 to 37 percent urbanization; therefore, it is not possible to determine whether their study would have detected effects at lower thresholds of urban land.

Studies examining the biotic impacts of IS show a range of responses. Coles et al. (2010) and Moore and Palmer (2005) conclude linear relationships between IS and biotic variables without thresholds. However, most of the studies we reviewed did identify thresholds. Schiff and Benoit (2007) identified impairment starting at 5 percent IS in their study of macroinvertebrates. Stanfield and Kilgour (2006) found changes in fish and benthos assemblages from less 3 percent to 10 percent IS with little additional changes above 10 percent IS. Weiskel (2010) found that median fluvial fish density approaches zero around 10 to 15 percent IS. Fitzpatrick et al. (2004) used indices to rate the health of biota and found that “Excellent” and “Good” ratings were only found in watersheds with less than 6 percent urban land. In examining the effect of IS on specific fish species, Wenger et al. (2008) found that above 2 percent IS the probability of occurrence for some species was zero. Riley et al. (2005) also found negative effects above 8 percent urban land use. Other studies had conclusions more similar to the studies on hydrogeomorphic variables in that they found effects on biotic variables above approximately 10 percent (Klein 1979; Jones and Clark 1987; Scheueler and Galli 1992; Shaver et al. 1995; Steedman 1988; Roy et al. 2003; Steward 1983; Booth 1991; Luchetti 1993; Booth and Jackson 1997). A study by Black and Veatch (1994) noted a threshold of 30 percent. However, it should also be noted that the studies that identified 10 percent or greater IS as a threshold in demonstrating environmental impacts, also specified that after this threshold there is a “sharp decline” (Scheueler and Galli 1992), “rapid decline” (Booth 1991), and “probably irreversible” (Booth and Jackson 1997) change in the response variable(s).

2. Hydrogeomorphology

Changes in the hydrologic regime of watersheds due to land use change are well-characterized and widely documented. There is less direct research on the nature of channel alteration that results from these hydrologic changes. While most studies draw similar conclusions about the physical effects of urbanization on hydrology and geomorphology, the parameters used for describing urban development and quantifying the environmental changes vary greatly. For example, urbanization may be measured by urban land area, high density residential area, total impervious area or effective impervious area. Even differences in impervious cover estimation methods can be significant (20-40% error within a land use category) (Ackerman and Stein 2008). For hydrologic parameters, frequently cited parameters include the magnitude, frequency and duration of daily, monthly, seasonal and annual low and peak flows. In addition, some studies compare across watersheds while others look at temporal trends in one watershed. These factors introduce significant challenges in comparing across studies.

a. Hydrologic Alteration

There is consistent agreement and well documented studies of the impacts of urbanization on altering hydrologic regimes and they are generally described in the following interrelated categories:

- Shorter lag time/Faster in-stream response to precipitation/”Flashiness”(Burns, Vitvar et al. 2005; Roy, Freeman et al. 2005; Schoonover, Lockaby et al. 2006; Chang 2007; Praskievicz and Chang 2009; Poff, Richter et al. 2010)
- Increased runoff volume (In, Brannan et al. 2003; White and Greer 2006; Line and White 2007; Cuo, Lettenmaier et al. 2009; Praskievicz and Chang 2009; Randhir and Hawes 2009; Graf)
- Increased peak rate of discharge or flooding (Rose and Peters 2001; In, Brannan et al. 2003; Burns, Vitvar et al. 2005; White and Greer 2006; Randhir and Hawes 2009; Arnold et al. 1982)
- Increased frequency of peak flows (Konrad and Booth 2005; Konrad, Booth et al. 2005; Randhir and Hawes 2009)
- Decreased recession time (Rose and Peters 2001; Burns, Vitvar et al. 2005; Konrad, Booth et al. 2005; Chang 2007)
- Decreased groundwater levels (Rose and Peters 2001)
- Decreased baseflow (Rose and Peters 2001; Chang 2007; Line and White 2007; Kauffman, Belden et al. 2009, Konrad and Booth 2005)

- Increased frequency and/or decreased volume of low flow (Rose and Peters 2001; Roy, Freeman et al. 2005; Cuo, Lettenmaier et al. 2009; Konrad and Booth 2005; Finkenbine et al. 2000)

The magnitude of these effects can be significant. For example, in comparing a watershed developed as part of a large residential subdivision to another that remained a mix of agricultural and forest land cover, it was observed that the runoff volume was 68% greater and baseflow was 100% reduced (i.e., provided 0% of streamflow) in the newly developed watershed (Line and White 2007). In another example where a "highly urbanized" watershed was compared with a "less-urbanized" and "non-urbanized" watersheds, peak flows were greater (30-100%), recession period and constant were lower (40-100%), baseflow recession constant was lower (35-40%), low flows were less (25-35%) and groundwater levels dropped lower in the highly urbanized watershed (Rose and Peters 2001). In comparing runoff from watersheds with increasing impervious surface cover to runoff from forested watersheds, Arnold and Gibbons (1996, as cited in Paul and Meyer 2001), found that increases in impervious surface of 10-20% increased runoff twofold, 35-50% increased runoff by a factor of three, and greater than 75% increased runoff by more than a factor of five.

The complexities of measuring the effect of urbanization in the environment, as mentioned before, are evident in a few studies. For example, Poff, Bledsoe, et al. (2006) compared 158 watersheds across four large hydrologic regions of the United States spanning a range of land cover compositions. While such a wide range of conditions did not yield a consistent hydrologic response across all regions, the authors were still able to conclude that, in general, urbanization induced a greater hydrologic response than similar proportions of agricultural land cover. When only examining watersheds with greater than 15% urban land cover, hydrologic responses were more consistent with other studies (Poff, Bledsoe, et al. 2006). Another illustration is provided in a study by Burns, Vitvar et al. (2005) which compared high density and medium density residential and undisturbed watersheds. Consistent with other studies, peak discharge increased, recession time decreased, and lag time for the arrival of peak flow decreased in the more urbanized watersheds, but baseflow during the dry period was highest in high-density residential watershed because of septic effluent. The effects of the septic effluent also resulted in a similar residence time for baseflow for all three watershed (~30 weeks) (Burns, Vitvar et al. 2005).

Because of the complexity and interconnectedness of watershed hydrology and the single design approach of most traditional stormwater management techniques (e.g., delay peak flow), several papers advocated the use of stormwater management approaches that mimic the natural hydrologic regime (Roy, Freeman et al. 2005; Hood, Clausen et al. 2007; Walsh, Fletcher et al. 2009). Hood, Clausen et al. (2007) documented the differences between a low impact development (LID) and a traditional development. Several hydrologic parameters were significantly different for the LID development (and closer to predevelopment hydrology) including a longer time to peak discharge, 1100% lower peak discharge and 100% greater runoff threshold (Hood, Clausen et al. 2007).

Two of the reviewed studies translated the hydrologic regime changes into flooding related statistics. Villarini, Smith et al. (2009) calculated that the return interval of the annual peak discharge decreased from once every 5,000 years to once almost every 8 years within a 50 year time span. White and Greer (2006) documented the effects of 34 years of development with an increase in urban land use from 9 to 37 % resulting in increased median and minimum daily discharge, dry-season runoff, and flood magnitudes, which in turn altered the geomorphology and doubled the area of riparian vegetation.

b. Channel Alteration

The majority of the research on channel alteration due to urbanization is focused at a smaller spatial scale than hydrologic impacts. Several studies quantify the magnitude of change from field measurements and/or calibrated models indicating the rates of certain processes that are occurring as a result of changing hydrologic regimes. For example, one model, calibrated to parameters such as in-situ erosion measurements by submerged jet tests, found that as the frequency and magnitude of discharge increases, changes in rates of incision are nonlinear and ranged from 0-76 mm/year (Allen, Arnold et al. 2008).

In general, the following impacts have been documented:

- Incision/Downcutting (Poff, Bledsoe et al. 2006; Burcher, Valett et al. 2007; Buckingham and Whitney 2007; Leopold 1973)
- Increased cross-sectional area/Widening/Undercutting (Poff, Bledsoe et al. 2006; Galster, Pazzaglia et al. 2008; Arnold et al. 1982; Buckingham and Whitney 2007; Galster et al. 2008; Hammer 1972; Keen-Zebert 2007)
- Channel erosion (Konrad, Booth et al. 2005; Grable and Harden 2006; Poff, Bledsoe et al. 2006; Arnold et al. 1982; Graf 1975; Keen-Zebert 2007)
- Sediment starvation (Wolman 1967, Pizzuto, Hession et al. 2000, Paul and Meyer 2001)
- Change in streambed composition/ pool and riffle structures (Konrad, Booth et al. 2005; Grable and Harden 2006; Poff, Bledsoe et al. 2006; Burcher, Valett et al. 2007; Finkenbine et al. 2000; Keen-Zebert 2007)
- Stream bank destabilization (Arnold et al. 1982; Henshaw and Booth 2000; Finkenbine et al. 2000)

Most of these changes are attributed to increases in the total volume, peak rate, and frequency of stormwater runoff (Konrad, Booth et al. 2005; Poff, Bledsoe et al. 2006).

Other studies related observed effects directly to watershed total impervious area which explained 65-72% of channel capacity enlargement in a study by Poff, Bledsoe et al. (2006). Poff, Bledsoe et al. (2006) also provide an example of the extent of such changes: bankfull cross-sectional area increased by ~178% and the channel was incised with median full-channel capacities increaseding by ~340%. Such downcutting and widening has secondary effects such as cutting stream off from floodplains which in turn reduces the floodplain’s sediment retention and water quality functions (Poff, Bledsoe et al. 2006). In another study, a comparison of urban and rural watersheds in southeastern Pennsylvania showed that in the urban watersheds the median width of stream channels were 26% larger, the median sinuosity were 8% lower, and pools were 31% shallower (Pizzuto, Hession et al. 2000). In addition, Pizzuto, Hession et al. (2000) note the selective removal of sediment in the size range of 2-64 mm in urban streams.

An increase in channel size and the reduced inundation of floodplains are contrary to the impacts cited under Hydrologic Alterations where more frequent flooding was indicated by higher and more frequent peak flows. These diverging observations again show that impacts will vary significantly based on local conditions. Other complicating factors in assessing changes in river geomorphology include human channel adjustments (e.g., channelization, channel realignment) and the presence of dams, roads, and bridges. Paul and Meyer (2001) provide a summary of the complex spatial and temporal variation of the effects of urbanization depending on the amount of time since development and the localized effects of bridges and other structures in urban streams.

Other factors that complicate the analyses of channel alteration due to urban stormwater runoff are local geologic conditions, cohesive substrates and riparian vegetation which can mitigate the impacts of urbanized hydrologic regimes (Gregory and Chin 2002; McBride and Booth 2005; Cianfrani, Hession et al. 2006; Grable and Harden 2006; Kang and Marston 2006; Colosimo and Wilcock 2007). For example, McBride and Booth (2005) document improvement in the “physical stream conditions index” by passing through an intact riparian buffer segment, therefore, mitigating the impact of degradation if only measured downstream.

Noted authors among the Hydrogeomorphology literature include: Pitt, R., Booth, D.B., O’Driscoll, M., Clausen, J.C., Poff, N.L, Bledsoe, B.P., Scheueler T.R.

3. Water Quality

   a. Parameters of Concern

Studies of water quality impacts from stormwater and urbanization have been conducted in numerous states and regions at various scales, including stream-specific and watershed-specific impacts (e.g., Bannerman, Owens et al. 1993; Carle, Halpin et al. 2005). The available studies vary in focus, with some addressing a specific sub-set of stormwater pollutants (e.g., Davis, Shokouhian et al. 2001), while others are more comprehensive (e.g., Bannerman, Owens et al. 1993) or compare the characteristics of various pollutants such as the relative strength of first flush (Lee, Lau et al. 2004). Davis, Shokouhian et al. (2001) take the additional step of attempting to attribute pollutant loadings to specific non-point sources within the watershed. Gobel, Dierkes et al. (2007) conducted an intensive literature review on the concentrations and distribution of pollutants in surface water runoff with more than 300 references. A meta-analysis conducted by Schueler, Fraley-McNeal et al. (2009) summarizes the findings of approximately 250 studies which have used the impervious cover model to relate water quality and biological endpoints to urbanization.

Development density has consistently been correlated with decreased water quality (Carle, Halpin et al. 2005). Findings of the preliminary literature review for specific stormwater pollutants are discussed in the following subsections.

i. Sediment (TSS, turbidity, siltation)

Annual export of sediment has been shown to be 95% greater for developed areas compared to undeveloped (Line and White 2007) and most of the variation in TSS has been explained using several variables describing the extent and distribution of urban development (Carle, Halpin et al. 2005). The physical characteristics of road-way solids have been studied, including mass limitations and the impacts of first flush (Sansalone, Koran et al. 1998). TSS has also been shown to influence the distribution of metals in runoff (Herngren, Goonetilleke et al. 2005).

ii. Oil, Grease, and Surfactants (i.e., sheen causing pollutants)

Wu, Allen et al. (1998) derived long-term highway pollutant loadings to provide a basis for comparing the magnitude of highway run-off to other non-point sources. Statistical analysis has indicated that urban land surfaces are the primary nonpoint source of most volatile organic compounds, including those related to gasoline, and that surface water would be protected most effectively by controlling land surface sources (Lopes and Bender 1998). Mallin, Johnson et al. (2009) compared surfactant concentrations across urban, suburban, and rural streams. They found that urban surfactant concentrations are the highest (Mallin, Johnson et al. 2009).

iii. Nutrients (nitrogen, phosphorus)

Multiple studies have estimated the effect of impervious surfaces and urbanization on nutrient concentrations including their functional response to impervious surface, which may be non-linear (e.g., Carle, Halpin et al. 2005; Cunningham, O'Reilly et al. 2009). Annual export of nitrogen and phosphorus forms has been found to be 66 to 88% greater in developed areas compared to undeveloped areas (Line and White 2007). Sources of phosphorus in urban catchments include wastewater and fertilizers (Paul and Meyer 2001). Increased nitrogen concentrations from urban centers can extend for hundreds of kilometers (Paul and Meyer 2001). The composition of nutrients may also be different in baseflow than stormwater (Taylor, Fletcher et al. 2005).

Alkalinity and pH

Low pH has been observed in streams affected by development (Peters 2009) and changes in post-construction acidity have been measured (Chen, Viadero et al. 2009). As discussed by the Center for Watershed Protection (2006), pH is one of the factors which can influence metal toxicity and availability in sediments.

Heavy metals in stormwater partly occur as dissolved substances due to the low pH of stormwater (Gobel, Dierkes, et al. 2007). Gobel, Dierkes et al. (2007) discuss how pH increases during the first 2 mm of a stormwater event and afterwards decreases asymptotically. Runoff pH also varies for different surfaces, with higher pH observed in traffic-related surfaces than pervious surfaces and roofs (Gobel, Dierkes et al. 2007). Elevated conductivity is observed in most urban streams due increased ion concentrations including calcium, sodium, potassium, and magnesium. Chloride ion concentrations may be particularly high in areas where sodium chloride is used extensively for road deicing (Paul and Meyer 2001).

iv. Inorganic Pollutants

Multiple studies measure the concentrations of metals in-stream or in stormwater (e.g., Davis, Shokouhian et al. 2001; Gardner and Carey 2004; Gobel, Dierkes et al. 2007; May and Sivakumar 2009). In addition to industrial discharges, there are various non-point sources of metals in urban catchments: brake linings contain nickel, chromium, lead, and copper; tires contain zinc, lead, chromium, copper, and nickel; and engine parts contain nickel, chromium, copper, and manganese (Paul and Meyer 2001). Davis, Shokouhian et al. (2001) estimated loadings for four metals (lead, copper, cadmium, and zinc) from specific sources of runoff including building siding and roofs and automobile brakes, tires, and oil leakage. They noted that the refinement of the loadings predictions would require additional information on metals release and additional watershed characterization.

v. Conventional Organic Pollutants

The effects of storm runoff on conventional organic parameters are discussed in Chen, Viadero et al. (2009) and Peters (2009). Mallin, Johnson et al. (2009) indicates that impervious surface coverage and watershed development is strongly correlated with biochemical oxygen demand (BOD). Dissolved oxygen is often adversely affected by urban stormwater due to introduction of biodegradable materials introduced by stormwater flow and their retention and decay in downstream deposition areas and/or impoundments (Helms, Schoonover et al. 2009).

vi. Organic Toxics

Similar to other pollutants, concentrations of PAHs and other organic toxics have been found to be significantly related to urban cover; however, the factors governing strength, transport, and fate of hydrophobic compounds have been shown to vary across urban areas and watersheds (Bryant and Goodbred 2009). Automobiles have been identified as a high contributor of PAHs based on an analysis of molecular weight (Hwang and Foster 2008). Hwang and Foster (2008) show that stormwater is a major contributor of PCBs to tidal rivers.

Pesticide detection is high in urban streams due to their frequent use around homes, commercial and industrial buildings, and golf courses. Organochlorine pesticide concentrations can exceed those observed in intensive agricultural areas (Paul and Meyer 2001).

vii. Emerging Pollutants

Eriksson, Baun et al. (2007) discuss some of the typical (e.g., metals, PAHs) and atypical compounds (e.g., nonylphenol ethoxylates) found in urban stormwater. Bjorkland, Cousins et al. (2009) measured phthalates and nonylphenols in urban stormwater and sediment and found that the urban water system is a significant sink for these contaminants. Pollutants such as pharmaceuticals or steroid estrogens tend to be associated with effluent from wastewater treatment plants (e.g., Karthikeyan and Meyer 2006) or seepage from residential septic tanks (e.g., Swartz, Reddy et al. 2006).

viii. Pathogens

Bacteria and pathogens due to stormwater inputs are well-characterized in the scientific literature and typically impact human water uses. For example, data have shown that beaches next to rivers have the highest bacteria levels and that urban runoff is a major contributor to coastal pollution (Dwight, Semenza et al. 2002). Data indicate that both non-point sources and point sources contribute to fecal coliform loads in urban streams (Paul and Meyer 2001).

ix. Trash

Allison, Chiew et al. (1997) describes trash in stormwater as a gross pollutant and characterized its transport and management options. Multiple water bodies in California have a total maximum daily loads for trash in place or proposed. For example, a trash TMDL is in place for the Los Angeles River (California Regional Water Quality Control Board 2007) where trash is defined as litter and particles of litter, including cigarette butts, and stormwater is described as a contributor to this stressor. Water uses potentially impaired by trash include contact recreation, non contact recreation, freshwater habitat, wildlife habitat, estuarine habitat, marine habitat, rare, threatened or endangered species, migration of aquatic organisms and spawning, reproduction and early development of fish, commercial and sport fishing, and wetland habitat (California Regional Water Quality Control Board 2007).

x. Elevated Temperature

Stormwater temperature depends on various factors including the season, time of day, and type of land cover (Maestre and Pitt 2005). Rainfall simulations have been conducted to test the direct impacts of land-cover type on runoff temperature (Thompson, Kim et al. 2008). Herb, Janke et al (2008) predicts surface temperature by land cover type as part of a larger project to assess the impact of urban development on the temperature of surface runoff and coldwater streams. Urbanization affects multiple elements important to stream temperature including removal of riparian vegetation, decreased groundwater recharge, and the “heat island” effect (Paul and Meyer 2001).

b. Water Quality Impacts

There are numerous studies which address stream-specific or watershed-specific impacts due to a change in water quality (e.g., eutrophication) (e.g., Bowen and Valiela 2001; Bay, Jones et al. 2003). Initial findings from the literature associated with these impacts are addressed in the following sub-sections. There are also multiple literature reviews available which summarize impacts from changes in water quality resulting from runoff or urbanization (e.g., Makepeace, Smith et al. 1995; Allan 2004). Allan (2004) provides a literature review of impacts and pathway of influence of land-use on local habitat and biological diversity and Makepeace, Smith et al. (1995) summarizes literature with a focus on contaminant impacts onto specific chemical, physical, and biological parameters. Brabec, Schulte et al. (2002) reviews studies that identify thresholds of impervious surface for water quality degradation and discusses methodological refinements required for more accurate and usable parameters for impervious surface thresholds and watershed management.

i. Pollution/Toxicity

Multiple studies characterize the pollution impacts and toxicity of runoff and receiving waters (e.g., Pitt, Field et al. 1995; Bay, Jones et al. 2003). Bay, Jones et al. (2003) identified the extent of a toxic plume resulting from urban stormwater discharges into a California bay and discussed relationships with upstream urbanization and channel characteristics. Pitt, Field et al. (1995) characterized selected stormwater contaminants and found that 9% of samples were extremely toxic and 32% were moderately toxic; however, only a small fraction of the organic toxicants analyzed were frequently detected.

ii. Eutrophication

Bowen and Valiela (2001) indicates that urbanization has shifted the predominant source of nitrogen from atmospheric deposition to wastewater disposal and increased nitrogen loading. This has altered the assemblage of primary producers, resulting in estuary eutrophication. Phosphorus stored in soils due to fertilization can be mobilized by soil erosion and contribute to eutrophication (Paul and Meyer 2001).

iii. Turbidity/light availability

Walters, Roy et al. (2009) found that turbidity is a strong predictor of fish descriptors. However, the preliminary literature review yielded relatively few studies which specifically address impacts from turbidity and light availability related to runoff and development. This may indicate that episodic short-term stormwater event has transitory effect on light availability.

iv. Thermal Pollution

Available studies related to thermal pollution from runoff characterize the impacts of impervious surfaces on increasing temperature of runoff and the resulting changes in stream temperature (e.g., Herb, Janke et al. 2008; Thompson, Kim et al. 2008). Herb, Janke et al. (2008) found that increased warm water runoff can degrade stream habitat and used deterministic modeling to predict the thermal impact of individual storm events to identify factors affecting the severity of thermal impacts. Paul and Meyer (2001) summarize the results of multiple studies which found that urban streams were warmer in the summer and cooler in the winter than forested streams. Summer time storms can also result in greater temperature pulses in urban streams compared to forested streams due to runoff from heated impervious surfaces (Paul and Meyer 2001).

4. Impacts to Designated Water Use

The extent of the scientific literature varies markedly among the various designated water uses potentially impacted by stormwater. There is extensive literature regarding impacts to aquatic habitats (including fish and macroinvertebrates). Fewer studies related to drinking water and contact recreation were identified during this preliminary literature review; however, potential impacts are apparent. For example, stormwater related episodes of bacteria and pathogens in the water column have well-documented effects on contact recreation activities and water-borne diseases.

a. Drinking Water Supply and Quality

The literature contains multiple studies which address potential impacts to drinking water from stormwater (e.g., Thomas 2000; Gaffield, Goo et al. 2003). The infiltration of urban stormwater into groundwater has the potential to impact ground water quality. Thomas (2000) identified stormwater runoff as having substantial influence on ground water quality near Detroit, MI; however, none of the samples from domestic wells included in the survey contained contaminant levels in excess of drinking water standards. Gaffield, Goo et al. (2003) investigated the scale of public health risk from stormwater impact on drinking water based on turbidity data from municipally treated water. It studied the associated cost of illness caused by urbanization in selected U.S. cities and found that the estimated annual cost of waterborne illness was comparable to the long-term capital investment for improved treatment. Antecedent climatic conditions and rainfall intensity have been found to significantly explain inter-event variation in *E. coli* levels in waters with recreational uses and with potential use as an alternative water source (McCarthy, Mitchell et al. 2007).

In arid or densely populated areas stormwater harvesting has been suggested as a possible water supply source for potable reuse, non-potable reuse through dual-reticulation or non-potable industrial or irrigation reuse. A recent review of the use of stormwater and recycled water as alternative water resources estimated that stormwater could potentially supply around 2 percent of the total urban demand for Southeast Queensland, Australia (SKM and Queensland 2008).

b. Agricultural Water Quality and Supply

Generally, we did not identify articles that directly discussed the adverse effects of water quality degradation due to urbanization on agricultural irrigation. Stormwater runoff quality is generally considered sufficient to support use as an irrigation supply, given that agricultural irrigation is a typical use of “reclaimed” wastewater (i.e., treated or untreated wastewater treatment plant effluent) (Heaton 1981).

Stormwater impoundments could provide a local alternative source of irrigation water for agricultural supply. Shukla and Jaber (2003) evaluated the technical feasibility of using stormwater impoundments in agricultural areas as sources of water within the Caloosahatchee (FL) watershed. Such use of impoundments could also result in improved downstream water quality due to increased retention of nutrients through plant uptake and increased nutrient assimilation in the impoundments. Schwecke, Simmons et al. (2007) considered the sustainable use of stormwater for irrigation of a golf course and found that it may reduce problems generated by overuse of groundwater.

c. Industrial Water Quality and Supply

The effect of stormwater on industrial process water quality and supply is not well characterized, as the episodic nature of stormwater does not lend itself as a consistent source for industrial uses until provisions for storage and distribution can be made. However, stormwater inputs to larger water bodies could have an adverse effect. Using the analogy of industrial concerns about the quality of reclaimed sanitary water, it is likely that the following water quality issues could be of concern: bacterial and residual organic materials, ammonia, nutrients, suspended solids, scale formation, staining, and sulfate corrosion. So many specific industrial processes exist with differing water quality requirements that no meaningful criteria can be established generally for quality of raw water supplies (San Francisco Bay Regional Water Quality Control Board 2007). Treatment methods can be incorporated into industrial processes to prevent disruptions or malfunctions due to poor water quality, potentially making consistent water quality more important than actual water quality.

d. Contact Recreation

Contact recreational activities involve body contact with frequent and prolonged water contact, especially by children, where ingestion of water is reasonably possible. These uses may include: swimming, wading, water-skiing, skin and scuba diving, surfing, and whitewater activities. The discharge of untreated urban runoff onto public beaches has been found to increase human health risks and symptoms (Dwight, Baker et al. 2004) and data shows that beaches next to rivers have the highest bacteria levels (Dwight, Semenza et al. 2002). Exposure to high pathogen levels in swimmable waters has been linked to a number of adverse health effects, including gastrointestinal illness, respiratory illness, eye ailments, and ear ailments (Abt Associates 2006). The cost of illness associated with recreational exposure can be significant. For example, Dwight, Fernandez et al. (2005) estimated a public health burden of $3.3 million per year due to illnesses associated with coastal water pollution at two California beaches using a cost of illness approach.

e. Non-Contact Recreation

Non-contact recreational activities involve proximity to water, but without body contact with water or where ingestion of water would be unlikely. These uses may include: boating, fishing, beachcombing, camping, nature study, sightseeing and aesthetic enjoyment in conjunction with the above activities. No studies explicitly identified impacts to non-contact recreation (i.e., fishing, boating) in the review of the initial set of papers. Benefit valuation literature contains numerous studies that provide a link between water quality and the value of water-based recreation such as fishing and boating (U.S. EPA 2009b). Literature review on the valuation of benefits is being conducted under Work Assignment 1.

f. Aquatic Habitat

Relevant studies which demonstrate impacts to aquatic habitat have been conducted in numerous watersheds and regions throughout the U.S. with ranging levels of urbanization and impervious surface. Available studies also vary in scope, ranging from individual stream reaches to multiple watersheds in multiple regions. The literature also includes multiple literature reviews and summary reports of aquatic impacts (Spellerberg 1998; U.S.G.S 1999; Center for Watershed Protection 2003; Allan 2004).

i. Alteration of fish species composition

Burcher, Valett et al. (2007) describes a hierarchy of abiotic components including discharge, stream bank height, erosion, and deposition which impact fish assemblage. Urbanization and high impervious cover is associated with low fish abundance and richness (Morgan and Cushman 2005) and some studies have identified critical levels of impervious cover (Schiff and Benoit 2007; Wenger, Peterson et al. 2008). Hydrological variables related to catchment urbanization explain a substantial portion of fish assemblage, diversity, richness, and abundance (Roy, Freeman et al. 2007) and this species diversity, richness, and biotic integrity is lower in streams that received high frequency of spate flows (Helms, Schoonover et al. 2009). Stormwater contaminants, such as copper, have also been shown to result in increased fish mortality (Sandahl, Baldwin et al. 2007).

ii. Fish and Shellfish Contamination

Exposure to stormwater can lead to the bioaccumulation of nuisance or toxic chemicals or pathogens by fish and shellfish species, which may cause tainting and/or contamination of these organisms thereby rendering them unfit or unsafe for human consumption. Shellfish contamination is the most documented example since poor water quality and presence of pathogens in shellfish lead to shellfish bed closures (see Commercial fishery section below).

Fish living in stormwater treatment ponds have been shown to accumulate heavy metals in their tissues (Campbell 1994). Turtles in urban lakes have been shown to bioaccumulate lead into body and shell bone (Bishop, Savitzky et al. 2010).

iii. Alteration of Macroinvertebrate Species

Runoff contaminants including hydrocarbons and heavy metals as well as thermal pollution have been shown to impact the diversity and composition of macroinvertebrate assemblages (Maltby, Forrow et al. 1995; Beasley and Kneale 2002; Wang and Kanehl 2003; Moore and Palmer 2005). Morgan and Cushman (2005) found that macroinvertebrate taxa richness was inversely related to impervious cover, in fact, Walter, Roy et al. (2009) found that macroinvertebrate descriptors were better predicted by land cover whereas fish descriptors were better predicted by geomorphology.

iv. Biodiversity Impacts

Biodiversity has been shown to be inversely correlated to development as shown by the cumulative distribution function of aquatic invertebrates in relation to land use gradients which indicate decreases in species and taxa occurrence in relation to percentage of impervious surface (Utz, Hilderbrand et al. 2009). As described above, multiple studies of fish diversity (Morgan and Cushman 2005; Roy, Freeman et al. 2006) and macroinvertebrate diversity (Moore and Palmer 2005) indicate that biodiversity decreases with increases in impervious land cover.

v. Wildlife/Greenway Impacts

Fewer studies documenting impacts to wildlife and greenway were identified compared to fish and macroinvertebrate species; however, urbanization can result in substantial increases in the presence and abundance of invasive plant species such as *Phragmites* (King, Deluca et al. 2007). Development can also have a dramatic impact on riparian vegetation by altering streamflow (White and Greer 2006). Changes in amphibian (Riley, Busteed et al. 2005) and insect (Smith and Lamp 2008) communities have also documented in various studies.

g. Irrigation, Navigation, Flooding and Flood Storage

Changes in hydrogeomorphology and water quality due to urbanization have several secondary impacts that are not often the primary topic of peer-reviewed literature but are cited in background information or as the motivation for the study (Fang and Su 2006;

Cook 2007). For example, while flooding is not the primary topic of Fang and Su (2006), their modeling efforts are directed at simulating flash flooding associated with thunderstorms in urban areas. Also, in the Hydrologic Alterations section, we cited papers that document increases in peak flow which can be translated into increases in flooding probabilities as done by Villarini, Smith et al. (2009). In addition, localized flooding has also been documented due to the inefficiency or clogging of existing stormwater infrastructure which is expected to intensify with continued development and climate change (Despotovic, Plavsic et al. 2005).

In addition to the effects of hydrologic alterations, water quality impacts, specifically sedimentation, affect the frequency and extent of flooding. Clark, Haverkamp et al. (1985) estimated flooding damages of $1.5 billion ($2008) attributable to sediment discharges from increasing sedimentation of river beds and decreased river capacity. Clark, Haverkamp et al. (1985) also address cost savings resulting from the prevention of sedimentation in navigable waterways, shipping channels, and harbors and discuss the impacts of sedimentation on reservoir capacity. While we did not identify any articles in this initial set that directly discussed the effects of water quality degradation due to urbanization on agricultural irrigation, we may be able to find such information in U.S. Department of Agriculture, Natural Resources Conservation Service or other similar government agency's literature.

h. Commercial Fisheries and Fish Consumption (fish and shellfish)

Stormwater inputs could potentially affect commercial fisheries at the local level. Due to the mobile nature of most fish that are fished commercially, there may be temporary avoidance of stormwater impacted areas. For commercial shellfishing beds, their fixed nature renders them more vulnerable to stormwater discharges and urban influences. For example, Duda and Cromartie (1982) assessed coastal North Carolina watersheds and documented sharp increases in residential development and corresponding shellfish bed closures (Duda and Cromartie, as cited in Glasoe and Christy 2004). Looking at the same tidal creek watersheds nearly 20 years later, Mallin et al. (2000; 2001) found that watersheds with less than 10% impervious cover had generally good water quality and large coastal areas open to shellfish harvesting; watersheds with 10 to 20 % impervious cover had impaired water quality and shellfish closures in the upper reaches; and watersheds with greater than 20 % impervious cover had severely polluted waters and were completely closed to shellfish harvesting (Mallin et al. 2000; 2001, as cited in Glasoe and Christy 2004).

i. Sedimentation of Reservoirs, Impoundments and Basins

Stormwater runoff and accompanying sediment loads reduce water capacity in large reservoirs (Novotny and Chesters 1981; as cited in USEPA 1995). In 1981 an average annual depletion rate of reservoir storage capacity was estimated at 0.2%/yr (Tourbier, 1981; as cited in USEPA 1995). Clark, Haverkamp et al. (1985) discussed the impacts of sedimentation on reservoir capacity. More recently, Smith, Renwick et al. (2002) estimated the total volume of sediment deposited in the approximately 43,000 large dams listed in the National Inventory of Dams (NID) at $1.67 \times 10^9 m^3$ per year.

There has been a historic shift in small pond construction from agricultural settings to urban ones, constructed primarily for storm water management and/or aesthetics. Estimates of the total amount of sedimentation in the millions of smaller impoundments not included in the NID are more difficult to make, but appears to be in the range of 0.1 to 1.8 x $10^9 m^3$ per year (Renwick, Sleezer et al. 2006).

While small ponds probably only account for a small percentage of the total water storage capacity in the United States, they are far more numerous and they exist higher in the drainage network (i.e., associated with smaller tributaries), where sediment yields per unit drainage area are high. In suburban areas ponds may temporarily serve as sinks for construction-period erosion, but thereafter sediment inputs are probably slow and pond lifespan is likely longer than for agricultural ponds (Renwick, Sleezer et al. 2006). On the other hand, increased runoff from urban land will tend to mobilize sediment in and adjacent to streams, increasing sediment loads to ponds.

j. Waste Assimilative Capacity/Biogeochemical Cycles

Waste assimilative capacity generally refers to the ability of a water body to carry and mitigate waste material without adverse effects on the environment or on users of its resources. When assimilative capacity is exceeded, water quality use and aquatic habitats may become impaired. Stormwater can mobilize and transport biodegradable organic compounds from watersheds to rivers, lakes, and coastal water bodies. This input would reduce the baseline waste assimilative capacity of the waters and when combined with the effluent discharges from permitted point sources (e.g., wastewater treatment plants) could adversely affect dissolved oxygen levels in aquatic habitats. Many states and governmental entities are now looking to inventory current wastewater and stormwater loadings to establish allowable thresholds to maintain sustainable assimilative capacity for high quality waters as well as future needs (e.g., MPCA 2008; State of Georgia 2008).

Human activities can lead to alterations in normal stream biogeochemistry in urban areas (Kaye, Groffman et al. 2006). Export of nitrogen and phosphorus from urban and heavily impervious area is typically very high. The composition of nitrogen in urban stormwater, during baseflows and storm events in Melbourne, Australia, was predominantly dissolved (about 80%), with ammonia the least-abundant form (11%). Concentrations of nitrogen species did not vary significantly between baseflow and storms, although the proportion of nitrogen in particulate form was higher during storm events (Taylor et al. 2005).

Human activities in urban areas can create hotspots for denitrification in stormwater detention basins, ditches, gutters, lawns and all places where water, nitrate and organic matter accumulate (Kaye, Groffman et al. 2006). In Phoenix, where riparian zones have been eliminated, Zhu et al. (2004) found stormwater detention basins to be especially important hotspots for denitrification. The denitrification rates, measured both as potential rates with substrate amendment (390–1,151 ngN2O–N per g soil per h), and as intact core fluxes (3.3–57.6 mg N per sq m per d), were comparable to the highest rates reported in literature for other ecosystems.

k. Aesthetics

Potential impacts of stormwater to aesthetic properties of water bodies include high turbidity, color, odor, oily films or residues, floating or beached litter, and unsightly scums or deposits. Litter in stormwater can cause significant aesthetic problems as well reduce the operating effectiveness of drainage systems (USEPA 1995). Under extreme conditions, these could constitute a violation of narrative water quality criteria. Benefit valuation literature contains numerous studies on the aesthetic preference for clean water and increased vegetation as reflected in property values and willingness-to-pay for scenic views. Literature review on the valuation of benefits is being conducted under Work Assignment 1.

l. Other Infrastructure / Property Impacts

Development and associated stormwater runoff can have physical impacts on infrastructure such as bridge scour and changes in flooding patterns, as discussed in previous sections. Additional literature addressing the physical effects of hydrogeomorphic changes, such as channel widening or bank erosion, on infrastructure and property will be targeted during future searches.

5. Land Based Impacts

Urban development can result in modification of the physical characteristics of the land (e.g., changes in the density and type of vegetative cover) and, as a result, changes in the environmental services which the land provides (e.g., Nowak and Crane 2000; Tilghman 1987). Implementation of stormwater BMPs and LID can improve land characteristics (e.g., density of vegetative cover) and thus potentially enhance a variety of environmental services including green house gas mitigation, atmospheric pollutant removal, heat regulation (i.e., heat island effect), flood storage, terrestrial habitat, and groundwater infiltration. Some stormwater BMPs such as construction of wetlands or retention ponds can also create or improve aquatic habitat in upland or wetlands areas. There are numerous studies which address impacts of changes in land characteristics on environmental services provided by land resources. Initial findings from the literature associated with these impacts are addressed in the following sub-sections.

a. Greenhouse Gas Mitigation (Carbon Sequestration)

i. Vegetative Cover

Changes in vegetative cover resulting from the implementation of stormwater BMPs could increase carbon storage and sequestration. Multiple models are available for quantifying the carbon storage and sequestration services associated with urban and non-urban forests (e.g., Nowak and Crane 2000; Smith et al 2006). Distinguishing between urban and non-urban settings when quantifying carbon sequestration is important due to differences in vegetation size and growth rates (Nowak and Crane 2002). The Urban Forest Effects Model (UFORE) (Nowak and Crane 2000; Nowak and Crane 2002) quantifies the structure and functions of urban forests including the total carbon stored and net carbon sequestered annually by urban trees and shrubs based on city-wide vegetation data, meteorological data, and pollution data. The model has been applied to various U.S. metropolitan areas such as Washington, D.C. (USDA 2006) and Chicago (USDA 2010; McPherson et al. 1997). An average tree in

Chicago sequesters about 10.8 lbs of carbon per year (USDA 2010), compared to about 11.8 lbs of carbon per year in Washington, D.C. (USDA 2006). UFORE forms the basis of the U.S. Forest Service's i-Tree software which can be used to estimate carbon sequestration benefits based on field data or land cover data (U.S. Forest Service et al. undated a; undated b). Models such as FORCARB2 are also available for the quantification of services non-urban forest habitats and regional table values are available by forest type (Smith et al. 2006). In addition, trees have indirect impacts on greenhouse gas mitigation through building energy use (McPherson and Simpson 1999). Emergent vegetation associated with stormwater BMPs could also provide carbon storage services (Euliss et al. 2006).

ii. Soils

We identified a number of published studies that provide information regarding soil organic carbon (SOC) levels in urban areas (e.g., Pouyat et al. 2002; Pouyat et al. 2006; Birdsey 1992). SOC values are included as one of six carbon pools in the U.S. Forest Service's forest ecosystem carbon tables which present estimates of carbon sequestered in forest stands throughout the United States by region and forest type (Smith et al. 2006). The other five ecosystem carbon pools are live trees, standing dead trees, understory vegetation, down dead wood, and the forest floor. There is some uncertainty regarding the timing of soil carbon storage services following landscape changes, with SOC levels likely increasing over many years (Pouyat et al. 2009). SOC values are highest in wetland soils (Euliss et al. 2006; Trettin and Jurgenson 2003), however the degree to which they act as carbon sources or sinks depends on multiple factors including age, operation, and environmental conditions such as location and climate (Kayranli et al. 2010).

b. Removal of Atmospheric Pollutants

Improvements in aboveground vegetative cover associated with implementation of stormwater BMPs and LID or changes in development patterns could result in a decrease in atmospheric pollutants levels. The amount of pollutants removed by vegetation depends on multiple factors including vegetation characteristics, climate, meteorological factors, and ambient pollutant concentrations (Nowak and Crane 2000). The available literature includes studies of pollutant assimilation for various plant taxa (e.g., Morikawa et al. 1998) and large-scale analyses of pollutant removal for metropolitan areas (USDA 2006; Nowak et al. 2006). The UFORE model (discussed above) provides estimates of city-wide removal by trees and shrubs for multiple pollutants including O_3, PM_{10}, NO_2, SO_2, and CO. The city-wide model results include ranges of removal for each pollutant based on Lovett (1994) to account for the range of in-leaf pollutant deposition velocities reported in the literature. The model can also provide removal estimates on a per tree or per acre basis for each pollutant (Nowak and Crane 2000; Nowak et al. 2006; USDA 2010; USDA 2006). As described above, U.S. Forest Service's i-Tree software incorporates UFORE to estimate atmospheric pollutant removal based on field data or land cover data (U.S. Forest Service et al. undated a; undated b). Brack's (2002) analysis for Canberra, Australia is an example of the quantification of pollutant removal services provided by trees planted within a city by applying available published values for services per square meter of tree crown. Deutsch et al. (2006) uses a modeling approach to quantify air quality benefits associated with green roofs in Washington, D.C. Reductions in ambient concentrations of air pollutants would likely improve human health. The UFORE model uses median values per unit of pollution to monetize air pollution benefits (Novak and Crane 2000). BenMAP, a GIS based program, is also available for quantifying and estimating the value of human health benefits associated with reductions in ambient air pollutants (U.S. EPA 2009a; 2008).

c. Heat Island Effects

Urban heat island conditions can be defined as heightened air and surface temperatures in urban areas relative to surrounding suburban and exurban areas (Soleki et al. 2005). Changes in development patterns and implementation of stormwater BMPs have the potential to reduce air temperatures through changes in vegetative cover and surface reflectivity (Sailor and Dietsch 2007). In their investigation for the Los Angeles Basin in Southern California, Kurn et al. (1994) found that near-surface temperatures over vegetated areas were 1-2˚C lower than background temperatures and that vegetation may lower urban temperatures by 1˚C. Available tools for assessing potential heat island impacts on urban climate, air quality, and energy consumption include the Heat Island Mitigation Screening Tool (MIST) (Sailor and Dietsch 2007). Changes in vegetation can also affect local temperatures and energy usage by altering windbreaks and shade patterns (McPherson and Simpson 1999). Stone and Norman (2006) found that the contribution of individual land parcels to regional heat island formation could be reduced by 40% by adopting specific land use planning policies, without modification to the size or surface reflectivity of the residential structure. The lowering of ambient temperature can also lead to reductions in ozone (Rosenfeld and Romm 1996), potentially resulting in human health benefits (Jacobson 2010). Heat island mitigation measures which reduce ambient temperatures can also reduce the number of heat-related urban mortalities from oppressive air masses or heat waves (Kalkstein and Sheridan 2003). Studies have estimated the functional relationship between mortality and air temperature for U.S. cities in various regions of the country (Kalkstein and Sheridan 2003; Kalkstein and Sheridan 2005; Davis et al. 2003) and some have estimated changes in mortality due to changes in vegetative cover or reflectivity (Kalkstein and Sheridan 2003; 2005).

d. Flooding (Flood Storage)

Wetlands have the potential to provide substantial flood control benefits (Mitsch and Gooselink 2000). Wetlands can provide significant flood control services depending on basin morphometry and location within the watershed; wetlands located along a river are likely to have a greater impact on downstream flooding than isolated basin wetlands (Mitsch and Gosselink 2000). Mitsch and Gooselink (2000) suggest based on examples from the Midwestern USA and Scandinavia that an optimum amount of wetlands in a landscape for flood storage might be around 3-7% in temperate zone watersheds. Other Stormwater BMPs such as extended detention basins, retention ponds, and wet swales also have the potential to reduce flood risk by storing floodwaters and reducing runoff volume (Metropolitan Council 2001). About 17% of all urban lands in the U.S. are located within the 100-year flood zone (Bernhardt and Palmer 2007). The restoration of wetlands and riverine areas for increased flood protection could reduce the risk of property loss and deaths (Bernhardt and Palmer 2007). However, the benefits of most stormwater management decisions are marginal in nature, producing small changes in flooding downstream or potentially shifting the distribution of flooding without eliminating flood risk (Braden and Johnston 2004). The HAZUS flood model, developed by FEMA, has been used to quantify flood risk and potential damages under the baseline conditions and with changes in flow regulation. For example, Joyce and Scott (2005) used HAZUS to quantify baseline flood risk and potential damages in Maryland counties and FEMA (2009) estimated changes in flood risk and potential damages associated with flow regulation features in King County, Washington. Johnston, Braden, and Price (2006) estimated the downstream flood mitigation benefits of storm water retention in an Illinois watershed by applying a formula-based flood damage approach to estimated changes in flood frequency. They estimated changes in flood frequency using Hydrological Simulation Program – Fortran (HSPF) and the U.S. Army Corps of Engineers' HEC-RAS model.

e. Groundwater Recharge

Changes in impervious cover and the presence of BMPs could improve groundwater recharge by reducing stormwater runoff and promoting infiltration. Groundwater can provide drinking water services, provide water for agriculture or other human uses, and can contribute to the provision of ecological services (e.g., stream base-flow, groundwater-fed wetlands) and may function as a reserve stock of water (Mitsch and Gooselink 2000; Bergstrom et al. 1996). Analysis of changes in groundwater services can be challenging because it requires a clear definition of baseline and post compliance conditions including geographical extent of land development impacts to the aquifer (Bergstrom et al. 1996). Moreover, environmental services provided by groundwater also depend on year-to-year variability in water volume within the aquifer (Braden and Johnston 2004).

f. Terrestrial Habitat and Wildlife

Implementation of stormwater BMPs and shifts in development patterns could change the amount or quality of terrestrial wildlife habitat due to changes in the amount and nature of terrestrial vegetation. Stormwater BMPs such as urban forests and riparian buffers have the potential to provide suitable living space for wild plants and animals and suitable reproductive habitat (i.e., provide "habitat function") and thus generate ecological benefits (de Groot et al. 2002). Detention basins (wet and dry) can be constructed to meet multiple objectives of flood attenuation, water quality control, and wildlife habitat enhancement or mitigation (Sutula and Stein 2003).

Urban forests and parks are generally assumed to be critical to the maintenance of wildlife communities in urban/suburban settings. However, not all urban woodlands are equal in their ability to attract and support a variety of breeding species. For example, bird diversity and abundance differ with the physical characteristics of woodlands (size, shape, and isolation), the variety of microhabitats provided (layers), the amount of impervious surface, and the level of human activity (Tilghman 1987; Melles et al. 2003). Several studies have related vegetated habitat size and quality to the number and composition of urban bird communities (e.g., Tilghman 1987; Fernandez-Juricic and Jokimake 2001; Melles et al. 2003; Donnelly and Marzluff 2004; and Seigel et al. 2005). Melles et al. (2003) compared bird communities in park or urban forest areas along a rural-suburban-urban land use gradient and found declines in bird species richness in relation to increased urbanization gradient.

Riparian buffers often act as “greenways” or wildlife corridors allowing migration between fragmented portions of habitat within an urban land use matrix (Angold et al. 2006). Relatively small patches (0.65 ha) in urban settings may be comparable to mature forest and may be sufficient to preserve richness and mammalian assemblages in areas managed for passive recreation (Dickman 1987; Mahan and O’Connell 2005).

g. Upland and Wetland Aquatic Habitat

Installation of multi-purpose stormwater BMPs such as constructed wetlands and retention ponds could lead to an increase in the amount of aquatic habitat and, as a result, in the number and richness of aquatic communities (amphibians, fish, insect, and waterfowl). Recently, multipurpose stormwater BMPs or dedicated habitat wetlands in urban areas have been designed to include or emphasize habitat creation elements, particularly in arid climates (Sutula et al., 2003; 2008). In urban areas, where natural forests are distant, or arid regions, where the presence of water is the primary determinant of habitat, the vegetation within stormwater BMPs may provide the only viable habitat, particularly for water-dependent biota. Some investigators have expressed concern that some retention basins can act as ecological “traps” due to retention of pollutants (Battin 2004), however they can be important in habitats in areas with naturally low levels of wetland density (Brand and Snodgrass 2009).

Distance to riparian zone and pond age may be important factors in amphibian composition and richness in retention ponds (Birx-Raybuck et al. 2010; Merovich and Howard 2000). Snodgrass et al. (2000) also found that hydroperiod (i.e., timing and duration of seasonally saturated conditions with water present) is an important factor affecting amphibian species richness near Savannah, GA. Richness, however, was not correlated with wetland size. A similar conclusion was reached for amphibians located in 103 wetlands in southern New Hampshire, where different species were adapted to different hydroperiods (Babbit 2005). A study of suburban watersheds in northern Baltimore County MD found that most of the wetlands that had amphibian breeding activity (89%) were either stormwater retention basins or wetlands created by past human activity (i.e., previously disturbed) (Brand and Snodgrass 2009). However, Knutson et al. (1999) found a negative association between amphibian presence and urban lands compared to positive relationships between amphibian presence and forests, wetlands, and habitat complexity.

Changes in the availability of wetlands and upland open-water habitat can also impact bird species. Increased habitat heterogeneity and open-water habitat associated with treatment wetlands can increase avian abundance and result in a transition from passerine to waterfowl (Seigel et al. 2005). As a consequence of their design, stormwater basins can retain suspended solids including particulate-associated metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), and nutrients (Casey et al. 2005). The pollutants within stormwater basins could potentially impact birds which utilize the stormwater basins as habitat. Sparling et al. (2004) found that nesting success in stormwater basins was comparable to the national average, however, other reproductive factors may be impacted by elevated levels of zinc, either through toxicity or indirectly through food availability.

Aquatic insects also utilize stormwater retention ponds. Richness of Hemipteran species in retention ponds has been found to be negatively correlated with pond surface area, likely due to the presence of fish (Foltz and Dodson 2009).

h. Biodiversity

Urbanization tends to lead to community and species shifts, with native species replaced by opportunistic non-indigenous species more tolerant of man-made environments. Urban-gradient studies show that the numbers of non-indigenous species increase and native species decline moving toward urban centers for many taxa including plants, birds, and butterflies (McKinney 2002). However, urban parks can serve as important biodiversity "hotspots" for cities (Fernandez-Juricic adnd Jokimaki 2001)

In a New Jersey study, Ehrenfeld (2000) found that a high ability to store floodwaters and evidence of flooding was associated with greater plant diversity and presence of obligate wetland species but was also associated with poor habitat for vertebrates and increased presence of water-borne trash and exotic species. Wetlands with shorter hydroperiods were associated with higher quality of vertebrate habitat, however they were also associated with increased human disturbance, large-scale dumping of trash, and nitrate releases from soils (Ehrenfeld 2000). A concern has been raised in the literature as to whether the use of wetland systems for the treatment of contaminated surface water may be incompatible with the goal of aquatic habitat enhancement due to potential toxicity within the created wetlands (e.g., Helfield and Diamond 1997).

i. Recreation and Aesthetics

Development or implementation of stormwater BMPs could have both recreational and aesthetic impacts through changes in the amount and nature of vegetation, the quantity of habitat, and the quality of habitat. Provisioning of wildlife stocks for hunting purposes is one of the traditionally valued ecological benefits of wetlands and forested areas, particularly for wetlands located in rural areas (Mitsch and Gosselink 2000; de Groot et al. 2002). A study conducted by Murray et al. (2009) in the Mississippi Alluvial Valley found that increases in wetland habitat can lead to an increase in water fowl hunting activity. Parcel attributes such as size, tree cover, and proximity to urban centers have been shown to influence hunting decisions in upland areas (Shrestha and Alavalapati 2004). Expected changes in bird diversity and abundance associated with riparian areas, urban forests, and stormwater BMPs (e.g., Fernandez-Juricic adnd Jokimaki 2001; Siegel et al. 2005) could improve the quality or increase the number of recreational trips which include birding. The use multi-use stormwater BMPs such as neighborhood parks can also provide substantial recreational services to nearby residents in surburban or urban areas (e.g., Lee and Li 2009).

Aesthetic attributes of stormwater BMPs, in particular riparian buffer, wetlands, and urban forests, can impact property decisions and values in adjacent or nearby areas. Multiple studies in the literature evaluate property impacts related to various attributes including quantity of open space, proximity to urban parks, tree density, and other natural features (Nassauer et al. 2001; Manuel 2003; McConnell and Walls 2005; Mahan et al. 2000; Acharya and Bennett 2001; Doss and Taff 1996; Lee and Li 2009). For example, Doss and Taff (1996) found in St. Paul, MN that increased proximity to urban wetlands was associated with increased property values. Wetlands with open water and scrub-shrub were preferred over emergent vegetation and forested wetlands. This finding suggests that the value of aesthetic services provided by stormwater BMPs depends on the type and condition of vegetation associated with a given BMP.

4. Summary

This initial literature review demonstrated that there is a considerable amount of literature on the topic of stormwater and development and their impacts. Possible options for the next effort include completing full readings of articles cited to date, acquire articles cited in review articles and/or continue to search and acquire non-peer reviewed reports such as government and non-profit publications.

5. References

Abt Associates, Inc. (2006). "Benefits of Water Quality Monitoring at U.S. Coastal Beaches'.

Acharya, G. and LL. Bennett. (2001). "Valuing Open Space and Land-Use Patterns in Urban Watersheds." Journal of Real Estate Finance and Economics **22**(2): 221-237.

Ackerman, D. and E. D. Stein (2008). "Estimating the variability and confidence of land use and imperviousness relationships at a regional scale." Journal of the American Water Resources Association **44**(4): 996-1008.

Allan, J. D. (2004). "Landscapes and riverscapes: The influence of land use on stream ecosystems." Annual Review of Ecology Evolution and Systematics **35**: 257-284.

Allen, P. M., J. G. Arnold, et al. (2008). "Prediction of channel degradation rates in urbanizing watersheds." Hydrological Sciences Journal-Journal Des Sciences Hydrologiques **53**(5): 1013-1029.

Allison, R., F. Chiew, and T. McMahon (1997). "Stormwater gross pollutants." Industry Report. Cooperative Research Center for Catchment Hydrology.

Angold, P.G., J.P. Sadler, M.O. Hill, A. Pullin, S. Ruston, K. Austin, E. Small, B. Wood, R. Wadsworth, R. Sanderson and K. Thompson (2006). "Biodiversity in urban patches." Science of the Total Environment **360**: 196-204.

Arnold, C.L., P.J. Boison and P.C. Patton (1982). "Sawmill Brook: An Example of Rapid Geomorphic Change Related to Urbanization." The Journal of Geology **90**(2) :155-166.

Arnold, C. L. and C. J. Gibbons (1996). "Impervious surface coverage: the emergence of a key environmental indicator." American Planners Association Journal **62**:243–58. *As cited in* Paul and Meyer (2001).

Babbit, K.J (2005). "The relative importance of wetland size and hydroperiod for amphibians in southern New Hampshire, USA." Wetland Ecology and Management **13**:269-279.

Bannerman, R. T., D. W. Owens, et al. (1993). "Sources of Pollutants in Wisconsin Stormwater." Water Science and Technology **28**(3-5): 241-259.

Battin, J. (2004). "When good animals love bad habitats: ecological traps and the conservation of animal populations" Conservation Biology **18**:1482-1491.

Bay, S., B. H. Jones, et al. (2003). "Water quality impacts of stormwater discharges to Santa Monica Bay." Marine Environmental Research **56**(1-2): 205-223.

Beasley, G. and P. Kneale (2002). "Reviewing the impact of metals and PAHs on macro invertebrates in urban watercourses." Progress in Physical Geography **26**(2): 236-270.

Bergstrom, J. C., K. J. Boyle, C. A. Job, and M. J. Kealy (1996). "Assessing the Economic Benefits of Groundwater for Environmental Policy Decisions." Water Resources Bulletin **32(**2): 279-291.

Bernhardt, E. S. and M. A. Palmer (2007). "Restoring streams in an urbanizing world." Freshwater Biology **52**:738-751.

Birdsey, R. A. (1992). "Carbon Storage and Accumulation in United States Forest Ecosystems." United States Department of Agriculture, Forest Service, General Technical Report WO-59.

Birx-Raybuck, D.A., S.J. Price, and M.E. Dorcas (2010). "Pond age and riparian zone proximity influences anuran occupancy of urban retention ponds." Urban Ecosystems **13**(2):181-190.

Bishop B., B. Savitzky, and T. Abdel-Fattah (2010). "Lead bioaccumulation in emydid turtles of an urban lake and its relationship to shell disease." Ecotoxicology and Environmental Safety (in press).

Bjorklund, K., A. P. Cousins, et al. (2009). "Phthalates and nonylphenols in urban runoff: Occurrence, distribution and area emission factors." Science of the Total Environment **407**(16): 4665-4672.

Black and Veatch 1994, as cited in Horner et al. 1999, complete citation forthcoming.

Bledsoe, B. P. and C. C. Watson (2001). "Effects of urbanization on channel instability." Journal of the American Water Resources Association. **37:** 255-270.

Booth 1991, as cited in Horner et al. 1999, complete citation forthcoming.

Booth, D. B., D. Hartley, et al. (2002). "Forest cover, impervious-surface area, and the mitigation of stormwater impacts." Journal of the American Water Resources Association **38**(3): 835-845.

Booth, D. B. and C. R. Jackson (1997). "Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation." Journal of the American Water Resources Association **33**(5): 1077-1090.

Bowen, J. L. and I. Valiela (2001). "The ecological effects of urbanization of coastal watersheds: historical increases in nitrogen loads and eutrophication of Waquoit Bay estuaries." Canadian Journal of Fisheries and Aquatic Sciences **58**(8): 1489-1500.

Brabec, E., S. Schulte, et al. (2002). "Impervious surfaces and water quality: A review of current literature and its implications for watershed planning." Journal of Planning Literature **16**(4): 499-514.

Brabec, E. A. (2009). "Imperviousness and Land-Use Policy: Toward an Effective Approach to Watershed Planning." Journal of Hydrologic Engineering **14**(4): 425-433.

Brack, C. L. (2002). “Pollution mitigation and carbon sequestration by an urban forest.” Environmental Pollution **116**: S195-S200.

Braden, J. B. and D. M. Johnston (2004). “Downstream Economic Benefits from Storm-Water Management.” Journal of Water Resources Planning and Management **130**(6): 498-505.

Brand, A.B. and J. W. Snodgrass (2009). “Value of artificial habitats for amphibian reproduction in altered landscapes.” Conservation Biology **24**: 295-301.

Bressler, D. W., M. J. Paul, et al. (2009). "Assessment Tools for Urban Catchments: Developing Stessor Gradients. " Journal of the American Water Resources Association **45**(2): 291-305.

Bryant, W. L. and S. L. Goodbred (2009). "The response of hydrophobic organics and potential toxicity in streams to urbanization of watersheds in six metropolitan areas of the United States." Environmental Monitoring and Assessment **157**(1-4): 419-447.

Buckingham, S.E. and J.W. Whitney (2007). “GIS Methodology for Quantifying Channel Change in Las Vegas, Nevada.” Journal of the American Water Resources Association. **43**(4): 888-898.

Burcher, C. L., H. M. Valett, et al. (2007). "The land-cover cascade: Relationships coupling land and water." Ecology **88**(1): 228-242.

Burns, D., T. Vitvar, et al. (2005). "Effects of suburban development on runoff generation in the Croton River basin, New York, USA." Journal of Hydrology **311**(1-4): 266-281.

California Regional Water Quality Control Board (2007). “Trash Total Maximum Daily Loads for the Los Angeles River Watershed.” August 9, 2007.

Campbell, K.R (1994). “Concentrations of Heavy Metals Associated with Urban Runoff in Fish Living in Stormwater Treatment Ponds.” Archives of Environmental Contamination and Toxicology 27:352-356.

Carriquiry, J. D., Sanchez, A., and V. F. Camacho-Ibar (2001). "Sedimentation in the northern Gulf of California after cessation of the Colorado River discharge." Sedimentary Geology **144**(1-2): 37-62.

Carle, M. V., P. N. Halpin, et al. (2005). "Patterns of watershed urbanization and impacts on water quality." Journal of the American Water Resources Association **41**(3): 693-708.

Casey,R.E., A.N. Shaw, L.R. Massal, and J.W. Snodgrass (2005). “Multimedia evaluation of trace metal distribution within stormwater retention ponds in surburban Maryland, USA.” Bull. Environ. Contam. Toxicology **74**: 273-280.

Center for Watershed Protection (2006). “Direct and Indirect Impacts of Urbanization on Wetland Quality.” 93pp.

Center for Watershed Protection (2003). "Impacts of Impervious Cover on Aquatic Systems." 158pp.

Chang, H. J. (2007). "Comparative streamflow characteristics in urbanizing basins in the Portland Metropolitan Area, Oregon, USA." Hydrological Processes **21**(2): 211-222.

Changnon, S. A. and N. E. Westcott (2002). "Heavy rainstorms in Chicago: Increasing frequency, altered impacts, and future implications." Journal of the American Water Resources Association **38**(5): 1467-1475.

Chen, Y. S., R. C. Viadero, et al. (2009). "Effects of Highway Construction on Stream Water Quality and Macroinvertebrate Condition in a Mid-Atlantic Highlands Watershed, USA." Journal of Environmental Quality **38**(4): 1672-1682.

Cianfrani, C. M., W. C. Hession, et al. (2006). "Watershed imperviousness impacts on stream channel condition in southeastern Pennsylvania." Journal of the American Water Resources Association **42**(4): 941-956.

Clark, E., J. A. Haverkamp, et al. (1985). Eroding Soils: The Off-Farm Impacts**:** 252.

Coles, J.F. et al. (2010). "Judging a Brook by its Cover: The Relation Between Ecological Condition of a Stream and Urban Land Cover in New England." Northeastern Naturalist **17**(1): 29–48.

Colosimo, M. F. and P. R. Wilcock (2007). "Alluvial sedimentation and erosion in an urbanizing watershed, Gwynns Falls, Maryland." Journal of the American Water Resources Association **43**(2): 499-521.

Cook, E. A. (2007). "Green Site Design: Strategies for Storm Water Management." Journal of Green Building **2**(4): 46-56.

Cunningham, M. A., C. M. O'Reilly, et al. (2009). "The Surburban Stream Syndrome: Evaluating Land Use and Stream Impariments in the Suburbs." Physical Geography **30**(3): 269-284.

Cuo, L., D. P. Lettenmaier, et al. (2009). "Effects of a century of land cover and climate change on the hydrology of the Puget Sound basin." Hydrological Processes **23**(6): 907-933.

Davis, R. E, P. C. Knappenberger, P. J. Michaels, and W. M. Novicoff (2003). “Changing heat-related mortality in the United States.” Environmental Health Perspectives **111**(14): 1712-1718.

Davis, A. P., M. Shokouhian, et al. (2001). "Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources." Chemosphere **44**(5): 997-1009.

deGroot, R.S., M.A. Wilson, and R.M.J. Boumans (2002). “A typology for the classification, description and valuation of ecosystem functions, goods and services”. Ecological Engineering **41**: 393-408.

Despotovic, J., J. Plavsic, et al. (2005). "Inefficiency of storm water inlets as a source of urban floods." Water Science and Technology **51**(2): 139-145.

Deutsch, B., H. Whitlow, M. Sullivan, and A. Savineau (2005). “Re-greening Washington, D.C.: A Green Roof Vision Based on Quantifying Storm Water and Air Quality Benefits”. Casey Trees Endowment Fund and Limno-Tech, Inc, August 24, 2005.

DiBari, J. N. (2007). "Evaluation of five landscape-level metrics for measuring the effects of urbanization on landscape structure: the case of Tucson, Arizona, USA." Landscape and Urban Planning **79**(3-4): 308-313.

Dickman, C.R. (1987). “Habitat fragmentation and vertebrate species richness in an urban environment.” J. Applied Ecology **24**: 337-351.

Donnelly, R. and J. R. Marzluff (2004). “Importance of reserve size and landscape context to urban bird conservation.” Conservation Biology **18**: 733-745.

Doss, C. R., and S. J. Taff (1996). “The Influence of Wetland Type and Wetland Proximity on Residential Property Values.” Journal of Agricultural and Resource Economics, **21**(1): 120-129.

Duda, A. and K Cromartie (1982). “Coastal Pollution from Septic Tank Drainfields.” Journal of the Environmental Engineering Division, American Society of Civil Engineers **108**(6): 1265-1279.

Duha, J. D., V. Shandas, et al. (2008). "Rates of urbanisation and the resiliency of air and water quality." Science of the Total Environment **400**(1-3): 238-256.

Dwight, R. H., D. B. Baker, et al. (2004). "Health effects associated with recreational coastal water use: Urban versus rural California." American Journal of Public Health **94**(4): 565-567.

Dwight, R. H., L. M. Fernandez, et al. (2005). "Estimating the economic burden from illnesses associated with recreational coastal water pollution - a case study in Orange County, California." Journal of Environmental Management **76**(2): 95-103.

Dwight, R. H., J. C. Semenza, et al. (2002). "Association of urban runoff with coastal water quality in Orange County, California." Water Environment Research **74**(1): 82-90.

Ehrenfeld, J.G. (2000). “Evaluating wetlands within an urban context.” Ecological Engineering **15**: 253-265.

Elmore, A. J. and S. S. Kaushal (2008). "Disappearing headwaters: patterns of stream burial due to urbanization." Frontiers in Ecology and the Environment. **6**: 308-312.

Eriksson, E., A. Baun, et al. (2007). "Selected stormwater priority pollutants - a European perspective." Science of the Total Environment **383**(1-3): 41-51.

Euliss, N.H., R.A. Gleason, A. Olness, R.L. McDougal, H.R. Murkin, R.D. Robarts, R.A Bourbonniere, and B.G. Warner (2006). “North American prairie wetlands are important nonforested land-based carbon storage sites.” Science of the Total Environment **361**: 179-188.

Fang, X. and D. H. Su (2006). "An integrated one-dimensional and two-dimensional urban stormwater flood simulation model." Journal of the American Water Resources Association **42**(3): 713-724.

FEMA (2009). “HAZUS Analysis for the Green River Valley.” Prepared by FEMA Region X Mitigation, October 6, 2009.

Fernandez-Juricic, F. and J. Jokimaki (2001). “A habitat island approach to conserving birds in urban landscapes: case studies from southern and northern Europe.” Biodiversity and Conservation **10**: 2023-2043.

Finkenbine, J.K., J.W. Atwater and D.S. Mavinic (2000). “Stream Health After Urbanization.” Journal of the American Water Resources Association **36**(5): 1149-1160.

Fitzpatrick, F.A. et al. (2004). “Urbanization Influences on Aquatic Communities in Northeastern Illinois Streams.” Journal of the American Water Resources Association **40**(2): 461-475.

Foltz, S.J. and S.I. Dodson (2009). “Aquatic Hemiptera community structure in stormwater retention ponds; a watershed land cover approach.” Hydrobiologia **621**: 49-62

Gaffield, S. J., R. L. Goo, et al. (2003). "Public health effects of inadequately managed stormwater runoff." American Journal of Public Health **93**(9): 1527-1533.

Galster, J. C., F. J. Pazzaglia, et al. (2008). "Measuring the impact of urbanization on channel widths using historic aerial photographs and modern surveys." Journal of the American Water Resources Association **44**(4): 948-960.

Gardner, C. B. and A. E. Carey (2004). "Trace metal and major ion inputs into the Olentangy River from an urban storm sewer." Environmental Science & Technology **38**(20): 5319-5326.

Glasoe, S. and A. Christy (2004). "Literature Review and Analysis: Coastal Urbanization and Microbial Contamination of Shellfish Growing Areas." Puget Sound Action Team, State of Washington, Olympia, Washington.

Gobel, P., C. Dierkes, et al. (2007). "Storm water runoff concentration matrix for urban areas." Journal of Contaminant Hydrology **91**(1-2): 26-42.

Grable, J. L. and C. P. Harden (2006). "Geomorphic response of an Appalachian Valley and Ridge stream to urbanization." Earth Surface Processes and Landforms **31**(13): 1707-1720.

Graf, W.L. (1975). "The Impact of Suburbanization on Fluvial Geomorphology." Water Resources Research **11**(5): 690-692.

Gregory, K. J. and A. Chin (2002). "Urban stream channel hazards." Area **34**(3): 312-321.

Hall, S. J., B. Ahmed, et al. (2009). "Urbanization Alters Soil Microbial Functioning in the Sonoran Desert." Ecosystems **12**(4): 654-671.

Hammer, T.R. (1972). "Stream Channel Enlargement due to Urbanization." Water Resources Research **8**(6): 1530-1540.

Heaton, R. D. (1981). "Worldwide Aspect of Wastewater Reclamation and Reuse". pp. 43-74 In: F. M. D'Itri, J. Aguirre-Martinez, and M. Athle-Lambarri (eds.) Municipal Wastewater in Agriculture. Academic Press, New York.

Hejazi, M. I. and M. Markus (2009). "Impacts of Urbanization and Climate Variability on Floods in Northeastern Illinois." Journal of Hydrologic Engineering **14**(6): 606-616.

Helfield, J.M. and M.R. Diamond (1997). "Use of constructed wetlands for urban stream restoration: a critical analysis." Environmental Management **21**: 329-341.

Helms, B. S., J. E. Schoonover, et al. (2009). "Asssessing Influences of Hydrology, Physiochemistry, and Habitat on Stream Fish Assemblages Across a Changing Landscape." Journal of the American Water Resources Association **45**(1): 157-169.

Herb, W. R., B. Janke, et al. (2008). "Thermal pollution of streams by runoff from paved surfaces." Hydrological Processes **22**(7): 987-999.

Herngren, L., A. Goonetilleke, et al. (2005). "Understanding heavy metal and suspended solids relationships in urban stormwater using simulated rainfall." Journal of Environmental Management **76**(2): 149-158.

Henshaw, P.C. and D.B. Booth (2000). "Natural Restabilization of Stream Channels in Urban Watersheds." Journal of the American Water Resources Association **36**(6): 1219-1236.

Hood, M. J., J. C. Clausen, et al. (2007). "Comparison of stormwater lag times for low impact and traditional residential development." Journal of the American Water Resources Association **43**(4): 1036-1046.

Horner 1997, as cited in Horner et al. 1999, complete citation forthcoming.

Horner, R., C. May, E. Livingston and J. Maxted (1999). "Impervious Cover, Aquatic Community Health, and Storm water BMPs: Is There a Relationship?" Proceedings of the Sixth Biennial Storm water Research and Watershed Management Conference. Southwest Florida Water Management District, Tampa, Florida.

Hwang, H. M. and G. D. Foster (2008). "Polychlorinated biphenyls in stormwater runoff entering the tidal Anacostia River, Washington, DC, through small urban catchments and combined sewer outfalls." Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering **43**(6): 567-575.

In, S. J., K. M. Brannan, et al. (2003). "Simulating hydrologic and water quality impacts in an urbanizing watershed." Journal of the American Water Resources Association **39**(6): 1465-1479.

Jacobson, Mark Z. (2010). "Enhancement of Local Air Pollution by Urban CO_2 Domes." Environmental Science and Technology 44(7): 2497-2502.

Johnston, D.M., J.B. Braden, and T.H. Price (2006). "Downstream Economic Benefits of Conservation Development." Journal of Water Resources Planning and Management **132**(1): 35-43.

Jones and Clark 1987, as cited in Horner et al. 1999, complete citation forthcoming.

Joyce, J.M. and M.S. Scott (2005). "An Assessment of Maryland's Vulnerability to Flood Damage." Maryland Department of the Environment, Flood Hazard Mitigation Section.

Kalkstein, L. S., and S. C. Sheridan (2003). "The impact of heat island reduction strategies on health-debilitating oppressive air masses in urban areas." A report to the U.S. EPA Heat Island Reduction Initiative, May 2003.

Kalkstein, L. S., and S. C. Sheridan (2005). “The impact of heat island reduction strategies on health-debilitating oppressive air masses in urban areas: a followup study.” A Report to the U.S. EPA Heat Island Reduction Initiative, March 2005.

Karthikeyan, K. G., and M. T. Meyer (2006). "Occurrence of antibiotics in wastewater treatment facilities in Wisconsin, USA." Science of the Total Environment. 361(1-3): 196-207.

Kang, R. S. and R. A. Marston (2006). "Geomorphic effects of rural-to-urban land use conversion on three streams in the central Redbed Plains of Oklahoma." Geomorphology **79**(3-4): 488-506.

Kauffman, G. L., A.C. Belden, et al. (2009). "Link between impervious cover and base flow in the White Clay Creek wild and scenic watershed in Delaware." Journal of Hydrologic Engineering. **14**: 324-334.

Kaye, J. P., P. M. Groffman, et al. (2006). "A distinct urban biogeochemistry?" Trends in Ecology & Evolution **21**(4): 192-199.

Kayranli, B., M. Scholz, A. Mustafa, and A. Hedmark (2010). “Carbon Storage and Fluxes within Freshwater Wetlands: a Critical Review.” Wetlands **30**: 111-124.

Keen-Zebert, A. (2007). “Channel Response to Urbanization: Scull and Mud Creeks in Fayetteville, Arkansas.” Physical Geography **28**(3): 249-260.

King, R. S., W. V. Deluca, et al. (2007). "Threshold effects of coastal urbanization on Phragmites australis (common reed) abundance and foliar nitrogen in Chesapeake Bay." Estuaries and Coasts **30**(3): 469-481.

Klein 1979, as cited in Horner et al. 1999, complete citation forthcoming.

Knutson, M.G., J.R. Sauer, D.A. Olsen, M.J. Mossman, L.M. Hemesath, and M.J. Lannoo (1999). “Effect of landscape composition and wetland fragmentation on frog and toad abundance and species richness in Iowa and Wisconsin, USA.” Conservation Biology **13**: 1437-1446.

Konrad, C. P., and D. B. Booth (2005). "Hydrologic Changes in Urban Streams and Their Ecological Significance." American Fisheries Society Symposium. **47**: 157-177.

Konrad, C. P., D. B. Booth, et al. (2005). "Effects of urban development in the Puget Lowland, Washington, on interannual streamflow patterns: Consequences for channel form and streambed disturbance." Water Resources Research **41**(7).

Kurn, D. M., and S. E. Bretz, B. Huang, and H. Akbari (1994). “The Potential for Reduction Urban Air Temperatures and Energy Consumption Through Vegetative Cooling.”

Lawrence Berkeley Laboratory, Energy & Environment Division, University of California Berkeley, Technical Report LBL-35320.

Lee, H., S. L. Lau, et al. (2004). "Seasonal first flush phenomenon of urban stormwater discharges." Water Research **38**(19): 4153-4163.

Lee, J. S. and M. H. Li (2009). “The impact of detention basin design on residential property value: Case studies using GIS in the hedonic price modeling.” Landscape and Urban Planning **89**: 7-16.

Leopold, L.B. (1973). “River Channel Change with Time: An Example.” Geological Society of America Bulletin **84**: 1845-1860.

Leopold, L. B. , R. Huppman, and A. Miller (2005). "Geomorphic effects of urbanization in forty-one years of observation." Proceedings of the American Philosophical Society **149:** 349-371.

Line, D. E. and N. M. White (2007). "Effects of development on runoff and pollutant export." Water Environment Research **79**(2): 185-190.

Lopes, T. J. and D. A. Bender (1998). "Nonpoint sources of volatile organic compounds in urban areas - relative importance of land surfaces and air." Environmental Pollution **101**(2): 221-230.

Lovett, G. M. (1994). “Atmospheric deposition of nutrients and pollutants in North America: an ecological perspective.” Ecological Applications **4**:629-650.

Luchetti 1993, as cited in Horner et al. 1999, complete citation forthcoming.

Maestre, A. and R. Pitt (2005). “The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information.” U.S. EPA.

Mahan, C. G. and T.J. O'Connell (2005). “Small mammal use of suburban and urban parks in central Pennsylvania.” Northeastern Naturalist **12**: 307-314.

Mahan, B. L., P. Polasky, and R. M. Adams (2000). “Valuing Urban Wetlands: A Property Price Approach.” Land Economics **76**(1): 100-113.

Makepeace, D. K., D. W. Smith, et al. (1995). "Urban Stormwater Quality - Summary of Contaminant Data." Critical Reviews in Environmental Science and Technology **25**(2): 93-139.

Mallin, M. A., V. L. Johnson, et al. (2009). "Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream." Environmental Monitoring and Assessment **159**(1-4): 475-491.

Mallin, M., S. Ensign, R. McIver, P.Shank and P. Fowler (2001). "Demographic, Landscape, and Meteorological Factors Controlling the Microbial Pollution of Coastal Waters." Hydrobiologia. **460**: 185-193.

Mallin, M., K.Williams, E. Esham and R. Lowe (2000). "Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds." Ecological Applications. 10(4):1047-1056.

Maltby, L., D. M. Forrow, et al. (1995). "The Effects of Motoway Runoff on Fresh-water Ecosystems: Field-study." Environmental Toxicology and Chemistry **14**(6): 1079-1092.

Manuel, P.M. (2003). "Cultural perceptions of small urban wetlands: cases from the Halifax regional municipality, Nova Scotia, Canada." Wetlands **23**: 921-940.

May, D. B. and M. Sivakumar (2009). "Prediction of heavy metal concentrations in urban stormwater." Water and Environment Journal **23**(4): 247-254.

McBride, M. and D. B. Booth (2005). "Urban impacts on physical stream condition: Effects of spatial scale, connectivity, and longitudinal trends." Journal of the American Water Resources Association **41**(3): 565-580.

McCarthy, D. T., V. G. Mitchell, et al. (2007). "Escherichia coli in urban stormwater: explaining their variability." Water Science and Technology **56**(11): 27-34.

McConnell, V., and M. Walls (2005). "The value of open space: Evidence from studies of nonmarket benefits." Washington, DC: Resources for the Future.

McKinney, M. (2002). "Urbanization, biodiversity and conservation." Bioscience **52**: 883-890.

McPherson, E.G., D. Nowak, G. Heisler, S. Grimmond, C. Souch, R. Grant, and R. Rowntree (1997). "Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project." Urban Ecosystems **1**: 49-61.

McPherson, E.G. and J. R. Simpson (1999). "Carbon ioxide reduction through urban forestry: guidelines for professional and volunteer tree planters." Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 237 pp.

Mejia, A. I. and G. E. Moglen (2009). "Spatial Patterns of Urban Development from Optimization of Flood Peaks and Imperviousness-Based Measures." Journal of Hydrologic Engineering **14**(4): 416-424.

Melles, S., S. Gleason, and K. Martin (2003). "Urban bird diversity and landscape complexity: species-environment associations along a multiscale habitat gradient." Conservation Ecology **7**: on-line.

Merovich C.E. and J.H. Howard (2000). "Amphibian Use of Constructed Ponds on Maryland's Eastern Shore." J. Iowa Acad. Sci. **107**: 151-159.

Metropolitan Council (2001). "Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates." Available at: http://www.metrocouncil.org/environment/Water/BMP/CH3_STRetenWetPond.pdf.

Minnesota Pollution Control Agency (MPCA) (2008). "What triggers a nondegradation review of potential impacts to high quality waters?" Water Quality Rulemaking Issue Paper #4. St. Paul, MN.

Mitsch W.J.and J.G. Gosselink (2000). "The value of wetlands: importance of scale and landscape setting." Ecological Engineering **35**: 23-33.

Moore, A. A. and M. A. Palmer (2005). "Invertebrate biodiversity in agricultural and urban headwater streams: Implications for conservation and management." Ecological Applications **15**(4): 1169-1177.

Morgan, R. P. and S. E. Cushman (2005). "Urbanization effects on stream fish assemblages in Maryland, USA." Journal of the North American Benthological Society **24**(3): 643-655.

Morikawa, H., A. Higaki, M. Nohno, M. Takahashi, M. Kamada, M. Nakata, G. Toyohara, Y. Okamura, K. Matsui, S. Kitani, K. Fujita, K. Irifune, and N. Goshima (1998). "More than a 600-fold variation in nitrogen dioxide assimilation among 217 plant taxa." Plant, Cell and Environment **21**: 180-190.

Murray, B., A. Jenkins, R. Kramer, and S.P. Faulkner (2009). "Valuing Ecosystem Services from Wetlands Restoration in the Mississippi Alluvial Valley." Ecosystem Services Series NI R 09-02. Nicholas Institute for Environmental Policy Solutions, Duke University. Ecosystem. 38 pp.

Nassauer, J.I., S.E. Kosek, and R.C. Correy (2001). "Meeting public expectations with ecological innovation in riparian landscapes." J. Am. Water Resources Assoc. **37**: 1439-1443.

Novotny, V. and G. Chesters (1981). Handbook of Nonpoint Source Pollution: Sources and Management. New York: Van Nostrand Reinhold Co.

Nowak, D.J. and D.E. Crane (2000). "The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions." In M. Hansen and T. Burk, eds. Proceedings: Integrated tools for natural resources inventories in the 21st century. IUFRO Conferences, 16-2- August 1998, Boise, ID; General Technical Report NC-212, U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. pp.714-720.

Nowak, D. J. and D. E. Crane (2002). “Carbon Sequestration by Urban Trees in the USA.” Environmental Pollution **116**: 381-389.

Nowak, D. J., D. E. Crane, and J. C. Stevens (2006). “Air pollution removal by urban trees and shrubs in the United States.” Urban Forestry & Urban Greening **4**: 115-123.

O'Driscoll, M.A., J.R. Soban, and S.A. Lecce (2009). "Stream channel enlargement response to urban land cover in small coastal plain watersheds, North Carolina." Physical Geography. **30:** 528-555.

Owens, P. N., R. J. Batalla, et al. (2005). "Fine-grained sediment in river systems: environmental significance and management issues." River Research and Applications. **21:** 693-717.

Paul, M. J. and J. L. Meyer (2001). "Streams in the urban landscape." Annual Review of Ecology and Systematics **32:**333-365

Peters, N. E. (2009). "Effects of urbanization on stream water quality in the city of Atlanta, Georgia, USA." Hydrological Processes **23**(20): 2860-2878.

Pielke, R. A., A. Beltran-Przekurat, et al. (2006). “Impacts of regional land use and land cover on rainfall: an overview.” Climate Variability and Change - Hydrological Impacts. S. Demuth, A. Gustard, E. Planos, F. Scatena and E. Servat. **308:** 325-331.

Pitt, R., R. Field, et al. (1995). "Urban Stormwater Toxic Pollutants - Assessment, Sources, and Treatability." Water Environment Research **67**(3): 260-275.

Pizzuto, J. E., W. C. Hession, and M. McBride (2000). "Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania." Geology. 28 (1): 79-82.

Poff, N. L., B. P. Bledsoe, et al. (2006). "Hydrologic variation with land use across the contiguous United States: Geomorphic and ecological consequences for stream ecosystems." Geomorphology **79**(3-4): 264-285.

Poff, N. L., B. D. Richter, et al. (2010). "The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards." Freshwater Biology **55**(1): 147-170.

Pouyat, R., P. Groffman, I. Yesilonis, and L. Hernandez (2002). “Soil carbon pools and fluxes in urban ecosystems.” Environmental Pollution **116**: S107-S118.

Pouyat, R.V., I.D. Yesilonis, and N. E. Golubiewski (2009). “A comparison of soil organic carbon stocks between residential turf grass and native soil.” Urban Ecosystems **12**: 45-62.

Pouyat, R. V., I. D. Yesilonis, and D. J. Nowak (2006). “Carbon Storage by Urban Soils in the United States.” Journal of Environmental Quality **35**: 1566-1575.

Praskievicz, S. and H. J. Chang (2009). "A review of hydrological modelling of basin-scale climate change and urban development impacts." Progress in Physical Geography **33**(5): 650-671.

Randhir, T. O. and A. G. Hawes (2009). "Watershed land use and aquatic ecosystem response: Ecohydrologic approach to conservation policy." Journal of Hydrology **364**(1-2): 182-199.

Renwick, W., R. Sleezer, R. Buddemeier and S. Smith (2006). “Small Artificial Ponds in the United States: Impacts on sedimentation and carbon budget.” Proceeding of the Eighth Federal Interagency Sedimentation Conference (8thFISC), April2-6, 2006, Reno, NV.

Richardson, E. V. and F. W. Huber (1991). "Evaluation of bridge vulnerability to hydraulic forces, stream instability, and scour." Transportation Research Board. 1290: 25-38.

Riley, S. P. D., G. T. Busteed, et al. (2005). "Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California streams." Conservation Biology **19**(6): 1894-1907.

Rose, S. and N. E. Peters (2001). "Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach." Hydrological Processes **15**(8): 1441-1457.

Rosenfield, A.H. and J.J. Romm (1996). “Policies to Reduce Heat Islands: Magnitudes of Benefits and Incentives to Achieve Them.” From the Proceedings of the 1996 ACEEE Summar Study on Energy Efficiency in Buildings, Pacific Grove, CA, 9:177.

Roy, A. H., B. J. Freeman, et al. (2007). "Riparian influences on stream fish assemblage structure in urbanizing streams." Landscape Ecology **22**(3): 385-402.

Roy, A. H., M. C. Freeman, et al. (2005). "Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams." Journal of the North American Benthological Society **24**(3): 656-678.

Roy, A. H., M. C. Freeman, et al. (2006). "Importance of riparian forests in urban catchments contingent on sediment and hydrologic regimes." Environmental Management **37**(4): 523-539.

Roy, A. H., A. D. Rosemond, M. J. Paul, D.S. Leigh, and J.B. Wallace (2003). “Stream macroinvertebrate response to catchment urbanisation.” Freshwater Biology **48**: 329–346.

Sailor, D. J. and N. Dietsch (2005). “The Urban Heat Island Mitigation Impact Screening Tool (MIST).” October 3, 2005.

Sandahl, J. F., D. H. Baldwin, et al. (2007). "A sensory system at the interface between urban stormwater runoff and salmon survival." Environmental Science & Technology **41**(8): 2998-3004.

San Francisco Bay Regional Water Quality Control Board (2007). “Water Quality Control Plan (Basin Plan) Chapter 2 ‘Beneficial Uses’.” Accessed at: http://www.swrcb.ca.gov/rwqcb2/water_issues/programs/planningtmdls/basinplan/web/bp_ch2.shtml

Sansalone, J. J., J. M. Koran, et al. (1998). "Physical characteristics of urban roadway solids transported during rain events." Journal of Environmental Engineering-Asce **124**(5): 427-440.

Schiff, R. and G. Benoit (2007). "Effects of impervious cover at multiple spatial scales on coastal watershed streams." Journal of the American Water Resources Association **43**(3): 712-730.

Schoonover, J. E., B. G. Lockaby, et al. (2006). "Impacts of land cover on stream hydrology in the west Georgia piedmont, USA." Journal of Environmental Quality **35**(6): 2123-2131.

Scheueler and Galli 1992, as cited in Horner et al. 1999, complete citation forthcoming.

Schiff, R. and G. Benoit (2007). "Effects of Impervious Cover at Multiple Spatial Scales on Coastal Watershet Streams.” Journal of the American Water Resources Association **43**(3): 712-730.

Schueler, T. R., L. Fraley-McNeal, et al. (2009). "Is Impervious Cover Still Important? Review of Recent Research." Journal of Hydrologic Engineering **14**(4): 309-315.

Schwecke, M. B. Simmons, and B. Maheshwari (2007). “Sustainable use of stormwater for irrigation case study: Manly Golf Course” The Environmentalist: **27**:51-61.

Seigel, A, C. Hatfield, and J.M Hartman (2005). “Avian response to restoration of urban tidal marshes in Hackensack Meadowlands, NJ.” Urban Habitats **3**: on-line.

Shaver et al 1995, as cited in Horner et al. 1999, complete citation forthcoming.

Shephard, J. M. (2005). "A review of current investigations of urban-induced rainfall and recommmendations for the future." Earth Interactions **9**.

Shrestha, R.K., and J.R.R. Alavalapati (2004). “Effect of ranchland attributes on recreational hunting in Florida: A hedonic price analysis.” Journal of Agricultural and Applied Economics **36**(3): 63-772.

Shukla, S. and F.H. Jaber (2006). “Stormwater as an Alternative Source of Water Supply: Feasibility and Implications for Watershed Management.” Institute of Food and Agricultural Sciences, University of Florida. Florida Cooperative Extension circular #1493.

SKM and Queensland Water Infrastructure Pty Ltd (2008). Review of Urban Stormwater Harvesting. Cornell Wagner Pty Ltd. Queensland, Australia.

Smith, J.E, L.S. Heath, K.E. Skog, and R.A. Birdsey (2006). “Methods for Calculating Forest Ecoystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.” USDA Forest Services, Northeastern Research Station, General Technical Report NE-343.

Smith, R. F. and W. O. Lamp (2008). "Comparison of insect communities between adjacent headwater and main-stem streams in urban and rural watersheds." Journal of the North American Benthological Society **27**(1): 161-175.

Smith, S., W. Renwick, J. Bartley and R. Buddemeier (2002). “Distribution and significance of small, artificial water bodies across the United States landscape.” The Science of the Total Environment **299**: 21-36.

Snodgrass, J.W., M.J. Komoroski, A.L.Bryan, and J. Burger (2000). “Relationships among isolated wetlands size, hydroperiod, and amphibian species richness: implications for wetlands regulation.” Conservation Biology **14**: 414-419.

Soleki, W.D., C. Rosenzweig, L. Parshall, G. Pope, M. Clark, J. Cox, and M. Wiencke (2005). “Mitigation of the heat island effect in urban New Jersey.” Environmental Hazards **6**: 39-49.

Sparling, D. W., J. D. Eisemann, and W. Kuenzel (2004). “Contaminant exposure and effects in red-winged blackbirds inhabiting stormwater retention basins.” Environmental Management **33**: 719-729.

Spellerberg, I. F. (1998). "Ecological effects of roads and traffic: a literature review." Global Ecology and Biogeography **7**(5): 317-333.

Stanfield, L.W. and B.W. Kilgour (2006). "Effects of Percent Impervious Cover on Fish and Benthos Assemblages and Instream Habitats in Lake Ontario Tributaries." American Fisheries Society Symposium **48**:577–599.

State of Georgia (2008). Comprehensive State-wide Water Management Plan. Georgia Water Council.

Steedman 1988, as cited in Horner et al. 1999, complete citation forthcoming.

Stevenson, J. C., L. G. Ward, and M. S. Kearney (1988). "Sediment transport and trapping in marsh systems: Implications of tidal flux studies." Marine Geology **80**(1-2): 37-59.

Steward 1983, as cited in Horner et al. 1999, complete citation forthcoming.

Stone, B. and J. M. Norman (2006). “Land use planning and surface heat island formation: A parcel-based radiation flux approach.” Atmospheric Environment **40**: 3561-3573

Sutula, M., J. Brown, E. Fetscher, M. Mattson, S. Madon, G. Santolo, E. Byron, and C. Stransky (2008). “Habitat value and treatment effectiveness of freshwater urban wetlands.” Final Report to Los Angeles Regional Water Quality Board for the Assessment of Effectiveness of Treatment Wetlands for Stormwater BMPs and Compatability with Wildlife Beneficial Use. Southern California Coastal Water Research Project. Technical Report No.559.

Sutula, M. and E. Stein (2003). “Habitat Value of Constructed and Natural Wetlands Used to Treat Urban Runoff: A Literature Review. Report prepared for the California State Coastal Conservancy.” Southern California Coastal Water Research Project. Technical Report No.338.

Swartz, C. H., S. Reddy, et al. (2006). "Steroid Estrogens, Nonylphenol Ethoxylate Metabolites, and Other Wastewater Contaminants in Groundwater Affected by a Residential Septic System on Cape Cod, MA." Environmental Science and Technology **40**(16): 4894–4902.

Taylor, G. D., T. D. Fletcher, et al. (2005). "Nitrogen composition in urban runoff - implications for stormwater management." Water Research **39**(10): 1982-1989.

Thomas, M. A. (2000). "The effect of residential development on ground-water quality near Detroit, Michigan." Journal of the American Water Resources Association **36**(5): 1023-1038.

Thompson, A. M., K. Kim, et al. (2008). "Thermal Characteristics of Stormwater Runoff from Asphalt and Sod Surfaces." Journal of the American Water Resources Association **44**(5): 1325-1336.

Tilghman, N.C. (1987). “Characteristics of urban woodlands affecting bird diversity and abundance.” Landscape and Urban Planning **14**: 481-495.

Tourbier, J. Toby (1981). Water Resources Protection Technology: A Handbook of Measures to Protect Water Resources in Land Development. Washington, DC: Urban Land Institute.

Trettin, C.C., and M.F. Jurgensen (2003). "Carbon cycling in wetland forest soils." p. 311-332. *In* J.M. Kimble et al. (ed.) The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect. CRC Press, Boca Raton, FL.

USDA (2010). "Assessing Urban Forest Effects and Values: Chicago's Urban Forest." Forest Service Northern Research Station, Resource Bulletin NRS-37.

USDA (2006). "Assessing Urban Forest Effects and Values: Washington, D.C.'s Urban Forest." Forest Service Northern Research Station, Resource Bulletin NRS-1.

U.S. EPA (2009). Environmental Benefits Mapping Analysis Program (BenMAP): Basic Information. Available at: http://www.epa.gov/air/benmap/basic.html

U.S. EPA (2009). "Environmental Impact and Benefits Assesssment for Final Effluent Guidelines and Standards for the Construction and Development Category." EPA-821-R-09-012.

U.S. EPA (2008). BenMAP Environmental Benefits Mapping and Analysis Program: User's Manual. Prepared by Abt Associates for the Office of Air Quality Planning and Standards. Available at: http://www.epa.gov/air/benmap/models/BenMapManualSept08.pdf

U.S. EPA (1995). "Storm Water Discharges Potentially Addressed by Phase II of the National Pollution Discharge Elimination System Storm Water Program." Report to Congress. Office of Water. EPA 833-K-94-002.

U.S. Forest Service, Davey, Arbor Day Foundation, Society of Municipal Arborists, and International Society of Arboriculture (undated a). "i-Tree Eco: User's Manual v3.1" Available at: http://www.itreetools.org/resources/manuals/i-Tree%20Eco%20Users%20Manual.pdf

U.S. Forest Service, Davey, Arbor Day Foundation, Society of Municipal Arborists, and International Society of Arboriculture (undated b). "i-Tree Vue: User's Manual v3.0" Available at: http://www.itreetools.org/resources/manuals/i-Tree%20Vue%20Users%20Manual.pdf

U.S.G.S., U.S. D.O.I. (2009). "Derivation of Nationally Consistent Indices Representing Urban Intensity within and across Nine Metropolitan Areas of the Conterminous United States." National Water Quality Assessment Program. Scientific Investigations Report 2008–5095.

U.S.G.S., U.S. D.O. I. (2004). "Urban Growth in American Cities." Geographic Analysis and Monitoring Program.

U.S.G.S., U.S. D.O.I. and U.S. D.O.T. (2002). "Field Observations and Evaluations of Streambed Scour at Bridges." Federal Highway Administration, Office of Infrastructure Research and Development. Publication No. FHWA-RD-01-041

U.S.G.S, U.S. D.O.I. (1999). “Assessing Biological Effects from Highway-Runoff Consituents.” 53pp.

U.S.G.S., U.S. D.O.I. (1997). “Stream Stability and Scour Assessments at Bridges in Massachusetts.” Open-File Report 97-558.

U.S.G.S., U.S. D.O.I. (1994). “Investigation of bridge scour at selected sites on Missouri streams.” Water Resources Investigations Report. 94-4200.

U.S.G.S., U.S. D.O.I. (1983). “Flood characteristics of urban watersheds in the United States.” Water Supply Paper 2207.

Utz, R. M., R. H. Hilderbrand, et al. (2009). "Identifying regional differences in threshold responses of aquatic invertebrates to land cover gradients." Ecological Indicators **9**(3): 556-567.

Villarini, G., J. A. Smith, et al. (2009). "Flood frequency analysis for nonstationary annual peak records in an urban drainage basin." Advances in Water Resources **32**(8): 1255-1266.

Walsh, C. J., T. D. Fletcher, et al. (2009). "Retention Capacity: A Metric to Link Stream Ecology and Storm-Water Management." Journal of Hydrologic Engineering **14**(4): 399-406.

Walters, D. M., A. H. Roy, et al. (2009). "Environmental indicators of macroinvertebrate and fish assemblage integrity in urbanizing watersheds." Ecological Indicators **9**(6): 1222-1233.

Wang, L. H. and P. Kanehl (2003). "Influences of watershed urbanization and instream habitat on macroinvertebrates in cold water streams." Journal of the American Water Resources Association **39**(5): 1181-1196.

Weiskel, P. April 13, 2010. Personal Communication.

Wenger, S. J., J. T. Peterson, et al. (2008). "Stream fish occurrence in response to impervious cover, historic land use, and hydrogeomorphic factors." Canadian Journal of Fisheries and Aquatic Sciences **65**(7): 1250-1264.

White, M. D. and K. A. Greer (2006). "The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Penasquitos Creek, California." Landscape and Urban Planning **74**(2): 125-138.

White, W. A., R. A. Morton, and C. W. Holmes (2002). "A comparison of factors controlling sedimentation rates and wetland loss in fluvial-deltaic systems, Texas Gulf Coast." Geomorphology **44**(1-2): 47-66.

Wolman, M. G. (1967). "A Cycle of Sedimentation and Erosion in Urban River Channels." Geography Annaler. 49A: 385-397.

Wu, J. S., C. J. Allan, et al. (1998). "Characterization and pollutant loading estimation for highway runoff." Journal of Environmental Engineering-Asce **124**(7): 584-592.

Zhu, W-X, N. Dillard, and N. Grimm (2004). “Urban nitrogen biochemistry: status and processes in green detention basins.” Biogeochemistry **71**:177-196.